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Discusses the economic considerations in selecting an optimal groundwater quality monitoring system. Section I argues that poor specification of the property rights in groundwater is a major cause of excessive pollution. Section II examines groundwater adjudication and legislation and notes that government intervention through the authority of PL 92-500 will take the form of government-established and -enforced groundwater quality standards. Section III discusses the overall costs and benefits to society involved in groundwater quality monitoring. Section IV discusses monitoring needs for establishment of quality standards and their enforcement, and develops a cost-benefit framework for the analysis of groundwater quality monitoring. Section V examines an alternative regulatory approach based on "waste relocation rights" for property owners. These rights would protect property owners' groundwater from pollution by others through specifying allowable pollutant levels. They would be transferable in the marketplace (like mineral rights) and enforcement of them would be carried out in the courts.

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TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS v

ACKNOWLEDGMENTS vi

SECTION I — INTRODUCTION 1

- Why Groundwater May Become Excessively Polluted 1
- Preventing Excessive Pollution of Groundwater 4
- Groundwater Management Objectives 4

SECTION II — INSTITUTIONAL AND LEGAL BACKGROUND 7

- The Legal Situation 7
- PL 92-500 (Federal Water Pollution Control Act) and PL 93-523 (Safe Drinking Water Act) 10
- EPA's Evolving Water Quality Strategy 11

SECTION III — HYDROGEOLOGIC CASE STUDY AND ECONOMIC PRINCIPLES 13

- Hydrogeologic Example 13
- Economic Principles 18

SECTION IV — MONITORING AND GROUNDWATER QUALITY STANDARDS 30

- Definitions of Information and Compliance Monitoring 30
- Information Monitoring 31
- Compliance Monitoring 34
- The Pragmatic Alternative—Second-Best Solutions 61

SECTION V — WASTE RELOCATION RIGHTS: AN ALTERNATIVE SYSTEM OF GROUNDWATER MONITORING AND POLLUTION CONTROL 66

- Administrative versus Nonadministrative Pollution Monitoring and Control 66
- Waste Relocation Rights 69
- Court Enforcement and Strict Liability 71
- The Zero Waste Relocation "Right" 73

(continued)

CONTENTS (continued)

Page

Setting the Initial Waste Levels 74
Exchanging Waste Relocation Rights 75
Restructuring Waste Relocation Rights 76
Sales of Land with Waste Relocation Rights 78
Waste Relocation Rights and Nonlandowners 81
An Appraisal of Some Potential Problems 82
Situations Inappropriate for Waste Relocation Rights 91
Conclusions 93

REFERENCES 94

APPENDIX 97

LIST OF ILLUSTRATIONS

Figure No.		Page
1	Geography of case study.	14
2	Hydrogeology of case study: elevation.	15
3	Hydrogeology of case study: plan.	17
4	Alternative steady-state time profiles of chloride concentration.	18
5	Farmer's total damages function.	21
6	Farmer's marginal damages function.	21
7	Oil company's total benefits function.	22
8	Oil company's marginal benefits function.	23
9	The efficient solution.	24
10	First limiting case.	28
11	Second limiting case.	29
12	The probability of detection function.	38
13	The gain from a standards violation.	39
14	Detection and the size of the violation.	39
15	The probability of detection and the severity of the violation.	41
16	The marginal cost of compliance monitoring.	42
17	The expected fine and the severity of the violation.	45
18	The expected fine and expenditure on compliance monitoring.	47
19	The expected cost and the severity of the violation.	47
20	The optimum violation.	49
21	The preference function.	49
22	The revised optimum violation.	50
23	The benefits from violation reduction.	52
24	Diminishing returns to violation reduction.	52
25	Compliance monitoring and the total social loss avoided.	53
26	The total benefits from compliance monitoring.	55
27	The marginal benefits from compliance monitoring.	55
28	The optimal probability of detection.	56
29	Second-best alternatives.	61
30	Land parcel diagram, chloride pollution example.	76
31	Seawater intrusion example.	92

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SECTION I

INTRODUCTION

This report presents an analytical framework for evaluating the economic issues raised by monitoring in support of the development and enforcement of groundwater quality standards. The discussion that follows incorporates certain legal and institutional aspects of various monitoring philosophies and methodologies with economic principles and issues. This analytical framework is presented in terms of case studies and theoretical situations, some aspects of which may appear to be in conflict with the mandates of the Federal Water Pollution Control Act, as amended by Public Law 92-500, and the Safe Drinking Water Act, Public Law 93-523. Accordingly, it is to be understood that the concepts, as presented in this discussion, do not necessarily reflect U. S. Environmental Protection Agency policy, although the document has been reviewed by the EPA and approved for publication.

Section II is a brief description of the existing institutional and legal structure; Section III presents a hydrogeological case study and develops the analytical framework in which the economic issues raised by groundwater monitoring will be discussed; Section IV is an economic analysis of the principles governing groundwater monitoring in support of (1) developing groundwater quality standards, and (2) enforcing compliance with those standards; Section V examines an alternative legal and institutional structure designed to ensure that an optimum use of the waste-assimilative capacity of the Nation's groundwater is achieved.

WHY GROUNDWATER MAY BECOME EXCESSIVELY POLLUTED

If (1) all markets were competitive, (2) market transactors had full information, (3) resource-owners put the resources they own to their highest valued use, and (4) enforceable property rights existed in all resources, then society's economic resources would be efficiently allocated. "Efficiently allocated" is used to mean that no other allocation would be possible which would make one transactor better off without making at least one other transactor worse off. Such an allocation is also described as pareto-optimal (Arrow 1951 and 1962, Arrow and Debreu 1954, Quirk and Saposnik 1968).

Under such an allocation of society's resources, groundwater resources would be used in optimal amounts for irrigation, cooling, drinking, etc., as well as for the disposal of wastes. Although the optimal portion of groundwater resources used for waste disposal under such an efficient allocation of resources may be small, it cannot be stressed too strongly that an abiding concern for the environment will not change the fact that wastes are an unavoidable byproduct of all man's activities. Recognizing that these wastes must be disposed of somewhere, the substantive questions of the optimum production of wastes and their optimum disposal must be addressed. Clearly, the Nation's aquifers, like every other sector of the environment, are a candidate repository for the disposal of some of society's wastes. The question, then, is not "whether" but "where" and "how much."

The evidence indicates that some of the Nation's groundwater (like our other environmental resources such as the air and surface waters) has become, or is becoming, excessively polluted. This means that groundwater is not being efficiently allocated among its alternative uses. On the contrary, its potential for irrigation, drinking, cooling, etc., is being abused by the overutilization of groundwater resources as a repository for society's wastes.

The reason that groundwater becomes excessively polluted is that the fourth condition necessary for the efficient allocation of resources, enforceable property rights, is not met with respect to groundwater. In general, property rights in groundwater are poorly specified.

If the property right in a resource is well specified, the owner has the maximum incentive to invest in the optimal amount of information on the alternative uses for his resource because he can appropriate to himself most of the rewards from his investment in acquiring that information. Indeed, the greater the appropriability of the benefits that can be derived from a resource, the greater the cost to an owner of not allocating that resource to its highest valued use and, therefore, the greater the incentive for economic efficiency. Hence, a better specification of property rights in resources leads to the appropriation of greater benefits from those resources by owners and this in turn leads to more efficient conservation of society's resources.

A burgeoning literature under the general rubric of "property rights" shows that different configurations of legal rights and duties impact on the resource owner's cost-reward calculus and generate different resource allocations. See, for example, Alchian (1961), Alchian and Kessel (1962), Coase (1960), Demsetz (1966 and 1967), De Vany et al. (1969), and Furubotn and Pejovich (1972).

The property rights to a resource are well specified when (1) the resource can be defined unambiguously (or, as in the case of land, where there are well-defined procedures for delimiting its boundaries), (2) the owner can capture all the benefits from the use of the resource to the exclusion of all other persons, (3) it can be protected at low cost against unauthorized use, and (4) title to the resource can be preserved and transferred among owners (a tract index, for example, in the case of land).

The importance of specifications can be appreciated best when there are no specifications. An ambiguous description of the resource raises negotiation or litigation costs and will, therefore, restrict exchanges; nonexclusivity in the appropriability of the benefits from the resource and high enforcement costs to prevent unauthorized use both attenuate the incentive to husband the resource, while imperfect titles and high exchange costs diminish the incentive to transfer the resource to higher valued uses.

The property rights in the Nation's groundwater are poorly specified on all four counts given above. Aquifers are poorly defined "common pools" with titles to their use and abuse not effectively preserved or transferred. In particular, lack of exclusivity in the appropriability of the benefits from aquifers and the high enforcement costs to prevent unauthorized use have given rise to two classic problems in the economics of hydrogeology. The first (associated with the lack of exclusivity in the appropriability of the benefits) is the problem of overuse or too rapid depletion of aquifers. (For an authoritative discussion of the problem see the appendix by Brown in Corker (1971).) The second (associated with the high enforcement costs to prevent unauthorized use) is the problem of excessive pollution of aquifers. When one party uses another party's resource without authorization, he thereby imposes uncompensated damages on the resource owner. An external cost is said to have been generated. (For the modern view of the connection between property right specifications and the existence of externalities see Buchanan and Stubblebine (1962), Cheung (1969), Coase (1960), Demsetz (1964 and 1969), Mishan (1971), and Stigler (1961). In general, externalities arise when problems exist with respect to the definition, exchange, policing, and enforcement of property rights.)

In the absence of any obligation to compensate those whose aquifer he is using as a waste disposal site, such waste disposal services appear free to the polluter. Polluters will, therefore, utilize such a service until the marginal private benefit obtained by them from using that service is driven down to zero—even though the marginal social cost may be positive and large. Consequently, the aquifer's waste receptor capabilities are abused and it becomes excessively polluted.

PREVENTING EXCESSIVE POLLUTION OF GROUNDWATER

In principle, there are two ways to prevent excessive pollution of groundwater. First, by government intervention in the effluent discharge process. Under this regime the government may either set, and enforce, groundwater quality standards by some form of direct regulations involving discharge licenses, or induce conformity to the standards by levying a tax on effluents or paying a subsidy for effluent reduction. (The monitoring implications of direct government intervention in the effluent discharge process are discussed in Section IV.) Second, the property rights to groundwater can be respecified so that they approach more closely the four requirements of a well-specified property right. (This possibility and the monitoring that would be implied are discussed in Section V.) Under this response to the problem of excessive groundwater pollution, the government's direct intervention is kept to a minimum. It merely performs its function of assigner of property rights through legislation and arbitration of disputes concerning property rights through its judicial media.

GROUNDWATER MANAGEMENT OBJECTIVES

Views similar to those outlined under this subheading have been expressed by the U. S. Council on Environmental Quality (1973). Efficient environmental decision-making requires that consideration be given to four categories of costs. First there are damage costs. These are costs which are generated directly by a polluting activity. With respect to groundwater resources, one example would be increased physiological damage caused by pollution of drinking water. Another example would be crop losses resulting from pollution of an irrigation well. Second, there are avoidance costs. These are costs which are incurred by society in order to avoid, or reduce, damage costs. With respect to groundwater resources, one example would be the importation of unpolluted water to replace that previously obtained from a well that has become polluted. Third, there are abatement costs. These are costs associated with the reduction of pollution. Such reduction of pollution can be achieved either by controlling the source or by treating the polluted water. With respect to groundwater resources, one example would be the deep injection into a safe geologic zone of noxious effluents previously disposed of in an aquifer. Fourth, there are transactions costs. Transactions costs include the cost of all those resources allocated to the establishment, and enforcement, of environment-preserving policies and regulations. With respect to groundwater resources, the most important example of a transaction cost, and of special relevance to this study, would be the cost of monitoring groundwater pollution either to generate information on quality and quantity or to detect violations of, and ensure compliance with, groundwater quality standards.

The essential principle to note is that these four cost categories are, in general, interdependent. Thus, any new groundwater quality policy will probably affect all four categories. For example, if a policy is introduced which is designed to reduce groundwater pollution, it will certainly reduce damage costs but may very well increase abatement, avoidance, and monitoring costs. Usually, each feasible groundwater quality policy will affect these four categories of cost differently. Obviously the only groundwater quality policy alternative that should be seriously considered for implementation is that set of policies for which the reduction in damage costs exceeds the net increase, if any, in avoidance, abatement, and monitoring costs. To go even further than this, the most efficient, or optimal, groundwater quality policy among the feasible set of alternatives is that policy which minimizes the sum of the damage costs, avoidance costs, abatement costs, and monitoring costs for a given groundwater pollution situation. Implicitly, the minimization of these costs is equivalent to the maximization of society's income or gross national product (GNP). Therefore, for this analysis the maximization of GNP has been adopted as the environmental management objective.*

To illustrate by example, sewer leakage is known to pollute groundwater and may, therefore, impose certain damage costs and avoidance costs. However, with present technology there is no way of controlling this source of pollution that does not impose abatement costs that are far in excess of the reduction in damage and avoidance costs which would be achieved. It follows that the efficient policy is not to monitor and abate this pollution source, but simply to accept the existing level of damage and avoidance costs.

Of course, in many other groundwater pollution situations the reduction in damage costs will exceed the increase in avoidance, abatement, and monitoring costs that bring those reductions about. The objective then becomes that of selecting the avoidance, abatement, and monitoring strategy which generates, at the margin, decreases in damage costs just equal to the increases in the avoidance, abatement, and monitoring costs required by the strategy.

The attainment of this objective will not simply involve the minimization of monitoring costs by the responsible government agency. For example, in any given groundwater pollution situation there may well be several different abatement strategies, each with an associated monitoring requirement, that would achieve the desired level of groundwater

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*For a comprehensive discussion of other possible objectives, see Dorfman and Dorfman (1972), Chapter 1. They observe, however, that "The GNP criterion is the most practicable one of all, in fact the only one that can be applied with much assurance." (p xxvii).

quality. If the public agency responsible for selecting among the abatement and monitoring strategies simply chooses that alternative which minimizes its own monitoring costs, this could imply higher private abatement costs with the result that the combined monitoring and abatement costs of that policy would be greater than the combined monitoring and abatement costs of some other strategy. Clearly, this would not be efficient from society's point of view.

SECTION II

INSTITUTIONAL AND LEGAL BACKGROUND

Section I points out that the major reason why the Nation's groundwater may become excessively polluted is that property rights in groundwater are poorly specified and so do not effectively protect aquifers against unauthorized use. Consequently, the capacity of aquifers to assimilate waste is being abused and uncompensated damages, or external costs, are being imposed on the owners of the resource. This section focuses first on the issue of unauthorized use by polluters, then on corrective efforts to date.

THE LEGAL SITUATION

Views expressed under this subheading rely heavily on Corker's authoritative discussion of groundwater law (Corker 1971, Chapter III). It may be stated as a general proposition that the law does grant a landowner a property right in the groundwater underlying his land. This title is granted under the doctrines of "absolute ownership," "reasonable use," "correlative rights," or "appropriative rights," depending on the State in which the landowner resides. In addition, a landowner whose groundwater is polluted by some other party may seek redress through the courts. Such redress may be sought under the traditional four concepts of negligence, nuisance, trespass, and, less frequently, strict liability. Of these legal remedies, resort is had most often to the law of nuisance. Thus, theoretically, the law stands behind a landowner who wishes to protect his groundwater against unauthorized pollution. The problem is that, in practice, the actual application of the law of nuisance is fraught with uncertainty. Corker states:

> Nuisance is an amorphous term which describes the substantial interference with the use of property for which a court will grant relief. To recover on a theory of nuisance, when pollution is intentional, as is often "legally" the case* one must in addition to proving the existence of a nuisance also prove that the activity is "unreasonable." What is

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*Corker's footnote states, "One is said to intend the results of his conduct if he continues to engage in an activity after recognition of its side effects."

> "unreasonable" depends upon a judicial weighing of an open ended list of factors, including the extent and character of the harm involved, the social value which the law attaches to the respective parties' activities, the suitability of each party's conduct to the locality, and the burden that would be imposed by compelling an interfering party to cease carrying on his activities. Because a particular activity will be characterized as a nuisance in one situation, but not in another, a user of land cannot always predict, in advance of a court room battle, whether he will be held liable for the pollution caused by his activities. Yet, despite difficulties with the concept of nuisance in the pollution field and elsewhere, legal critics have not found an acceptable substitute. (Corker, 1971).

The only legitimate inference that a landowner could make from this authoritative interpretation of the law of nuisance as applied to groundwater pollution is that his property right in underlying groundwater is decidedly shaky when it comes to its protection against unauthorized use by polluters. Given the uncertainty of retribution in the courts under the law of nuisance, it should not be found surprising that polluters have abused their neighbor's groundwater.

When not dealt with under the legal rubric of nuisance (and in the absence of negligence, trespass, or abnormally dangerous conduct), liability for pollution of groundwater has, instead, been dealt with under the doctrines of absolute ownership, reasonable use, correlative rights, or appropriative rights.

> Depending on the jurisdiction, the doctrines of absolute ownership, reasonable use, and occasionally the doctrines of correlative rights or prior appropriation have tended to be mechanically applied . . . . [Application of] the doctrines of absolute ownership, correlative rights, and prior appropriation to disputes among competing water and land users can produce surprising and undesirable results. Under the literal doctrine of absolute ownership, a water user will not be able to recover for injury to his water supply, even when the land user can foresee and avoid such damage. Under the doctrine of correlative rights a third party may be required to pay damages, even though injury is unforeseeable and his activity was a natural and legitimate use of his land. Under a strict reading of prior appropriation, a mining or land development corporation can be enjoined from use of land, even when the proposed operations will drain but one shallow neighboring well.

> The reasonable use doctrine in a third party setting is also unsatisfactory, although use of this doctrine has produced fewer disquieting results in the past. Courts have utilized this doctrine to prevent recovery of damages when injury was unforeseeable, a result consistent with tort doctrines of nuisance, and strict liability. This distinction between percolating water and subsurface streams was developed and has been utilized to prevent imposition of liability for unexpected results. It is uncertain, however, whether under a reasonable use theory, damages can be recovered because injury to "percolating" groundwater was a foreseen, but unavoidable, consequence of land use and the land operation was pursued in the face of this knowledge. If in determining whether a land use is "reasonable" the extent of damage to the aquifer and other surrounding circumstances are overlooked, the result will at times be clearly wrong. If, however, in the determination of whether a use is reasonable the gravity of the harm done to the water user is weighed against the utility of the land use, the result will be the same as under nuisance theory . . . (Corker, 1971; emphasis added).

It is clear that the attempted resolution of disputes over the liability for groundwater pollution in water doctrinal terms is as unsatisfactory as resolutions sought through the law of nuisance. Resource owners will not feel secure in their property and protected against unauthorized users when the law produces "surprising and undesirable results."

Two cases quoted in the American Law Reports, Annotated, Second Series (38ALR 2d), "Liability for Pollution of Substream Waters," illustrate by particular examples the uncertainty and arbitrariness which surround liability for groundwater pollution:

> Where a company drilling for and producing oil brought salt water to the surface . . . the fact that the company connected a pipeline conveying its salt water with a line of the sewer system of a city and the city permitted the salt water to flow into a canal, from where it seeped into the source of the water supply of the plaintiff, thereby damaging it, did not excuse the company from the liability for damages for allowing the salt water to leave its premises. Berry v. Shell Petroleum Co. (1934) 140 Kan 04, 33 P2d 953, reh den 141 Kan 6, 40 P2d 359.

In this case it would seem reasonable to have held the city guilty and the oil company innocent. But such was not the verdict. Conversely, consider:

> Phoenix v. Graham (1953) 349 Ill App 326, 110 NE2d 669, in which the plaintiffs sought recovery for contamination of their water well by salt water from the pits into which the water was diverted upon separation from the oil. The court, reversing a judgment for the plaintiffs, . . . pointed out that the cases in other jurisdictions are practically uniform that the operator is not liable to his lessor for salt-water damage unless it was caused by negligence in the operations.

In this case, it might seem reasonable to hold the oil company liable for its nuisance. However, such was not to be the appeal court's verdict. As might be expected, it does seem easier to obtain redress in the courts if negligence on the part of the polluter can be shown. However, this is little comfort to an owner of groundwater because, in practice, negligence is often not present even though pollution of his property occurs.

Even from this brief analysis of the application of the law of nuisance and various water doctrines to the problem of liability for groundwater pollution, it is apparent that aquifer owners are not secure in the protection of their property against unauthorized users. Consequently, it should be no surprise that such unauthorized use occurs and that the Nation's groundwater is threatened with excessive pollution. It is against this background of legal uncertainty that Corker felt compelled to recommend statutory, and publicly administered, water quality controls which would require permits for the execution of activities which are potentially harmful to the Nation's groundwater (Corker, 1971).

PL 92-500 (FEDERAL WATER POLLUTION CONTROL ACT) AND PL 93-523 (SAFE DRINKING WATER ACT)

Statutory, publicly administered, and permit-oriented legislation directed towards the protection of the Nation's water supplies in general, including its groundwater supplies, was enacted by Congress in October 1972 over the President's veto in the form of the Federal Water Pollution Control Act, PL 92-500. Analogous legislation designed to protect the Nation's drinking water supplies became law in December 1974 in the form of the Safe Drinking Water Act, PL 93-523.

PL 92-500's objective "is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (Section 101(a)). In pursuit of these objectives, "The [EPA] Administrator shall establish national programs for the prevention, reduction, and elimination of pollution and as part of such programs shall . . . establish, equip, and maintain a water quality surveillance system for the purpose of monitoring the quality of . . . groundwaters" (Section 104(a) (5)). Similarly, PL 93-523 obliges the EPA Administrator to ". . . establish recommended maximum contaminant levels for each contaminant which . . . may have any adverse effect on the health of persons (Section 1412 (b) (1) (B)). Before the Administrator may approve a State's regulatory program, he must be assured that the State's program includes "inspection, monitoring, recordkeeping, and reporting requirements" (Section 1421(b) (1) (C)).

In the larger sense, this report explores the issues involved in establishing, equipping, and maintaining alternative water quality surveillance systems in order to reveal the principles on which the selection of a preferred surveillance, or monitoring, strategy should be based.

EPA's EVOLVING WATER QUALITY STRATEGY

The obligation to implement PL 92-500 and PL 93-523 falls on the EPA. In execution of that responsibility, the EPA issued the second edition of its Water Quality Strategy Paper in March 1974 (USEPA, 1974). The EPA's strategy is not cast in concrete and a conscious effort has been made to ensure that "there is flexibility to adjust to . . . circumstances through periodic revisions" (USEPA, 1974). However, certain policies appear to be well-enough established to rely on them as guideposts to direct this inquiry. The most important of these is the policy to control pollution by a groundwater quality standards mechanism implemented through a permitting scheme. Consequently, this analysis is limited to monitoring in the context of such a permitting scheme and does not pursue the issues involved in monitoring if groundwater quality standards were to be achieved through an effluent charges scheme, a pollution reduction subsidy scheme, etc.* The only exception to this limitation occurs in Section V, which explores an alternative legal and institutional structure designed to ensure an optimum use of the waste-assimilative capacity of the Nation's aquifers.

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*It cannot be stressed too strongly that this restriction does NOT imply an opinion that direct regulation by a permit scheme is the most efficient form of groundwater pollution control. An elementary discussion of the pros and cons of different pollution control schemes is contained in the Fourth Annual Report of the U.S. Council on Environmental Quality (USCEQ, 1973); a more sophisticated treatment is contained in Mäler (1974).

In March 1974 the EPA concluded that its "review of FY 1974 monitoring activities indicates that . . . there is still a need to establish a basic national direction of effort" (USEPA, 1974). The remaining sections in this report are intended to help direct the Nation's groundwater monitoring effort along fruitful paths.

SECTION III

HYDROGEOLOGIC CASE STUDY AND ECONOMIC PRINCIPLES

This section and Section IV examine the monitoring implications of a government permitting scheme to prevent excessive groundwater pollution from effluent discharge.

Since groundwater is a relatively unfamiliar resource, a hypothetical case study is used to convey the minimum essential hydrogeologic information that is required to obtain an appreciation of the complications involved in monitoring. This hydrogeologic example is then used to illustrate the economic issues involved in groundwater quality control and its monitoring.

HYDROGEOLOGIC EXAMPLE

The hydrogeologic example involves a wide variety of factors which include the basic situation (parties involved, land use, etc.), geography, hydrogeology, existing groundwater pollution information, and the configuration of the pollution plume.

Pollution Situation*

The illustrative example is a simple one involving an oil company (Party _A_) and a farmer (Party _B_). Party _B_, the pollutee, uses a 100-gallon per minute (gpm) well located on his property for supplemental irrigation of 1000 acres of level land.† Although Party _B_ is not aware of it, his well is becoming polluted by an unlined oil-field brine disposal pit operated by Party _A_. The farmer uses his land to grow rice—a crop for which irrigation is mandatory, given the average local rainfall of 48 inches per year. Since the rain is fairly evenly distributed throughout the year, the well is used for irrigation only during the months of August and September. The farmland is easily converted to produce cotton, soy beans, and Bermuda grass—lower valued crops which are less sensitive to salt pollution and do not require irrigation, although irrigation greatly increases yields.

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*For an actual case study see USEPA (1972).

†An English-to-metric unit conversion table is appended to this report.

Geography

The geographic relationship between the disposal pit and the irrigation well is presented in Figure 1. The farmer's well is located 750 feet from the unlined disposal pit, and 250 feet from the property line. The eastern border of the farmer's land is an ocean coastline into which the groundwater ultimately flows and from which seawater may conceivably intrude.

A 500-milligram per liter (mg/l) isopollution contour is shown at time t_0 when pollution is detected at B's well. (An isopollution contour is defined by the locus of all points of equal pollution intensity.) This concentration level is of critical importance since rice is assumed to be insensitive to lower chloride concentration levels. The dimensions of the plume are not known to either party at this time; all that is known by B is that his well is polluted.

Hydrogeology

An unscaled elevation of the hydrogeological situation at time (t_0) is shown in Figure 2. The geology of the strata underlying the subject area is assumed to be known to the polluting oil company from its drilling

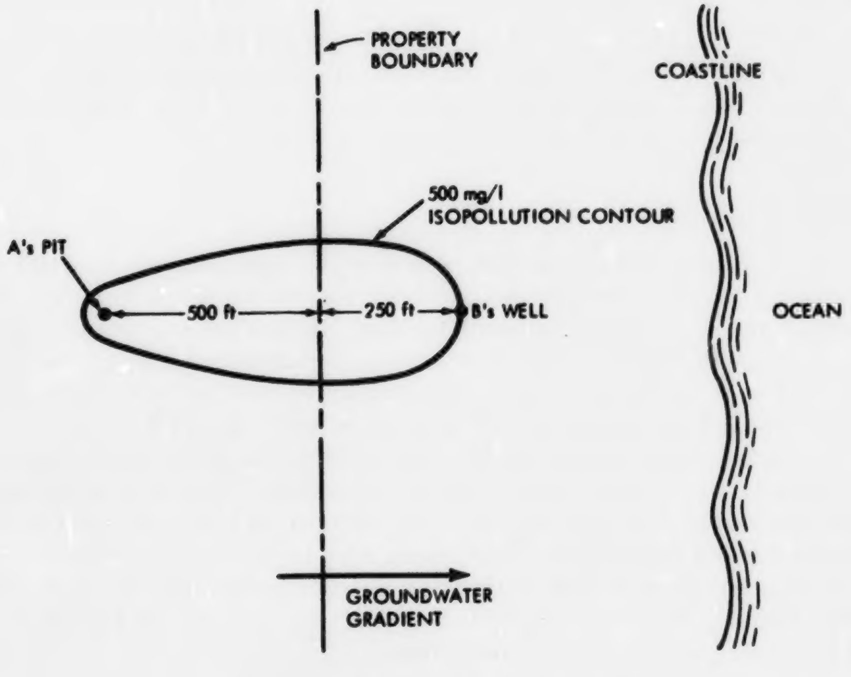

Figure 1. Geography of case study.

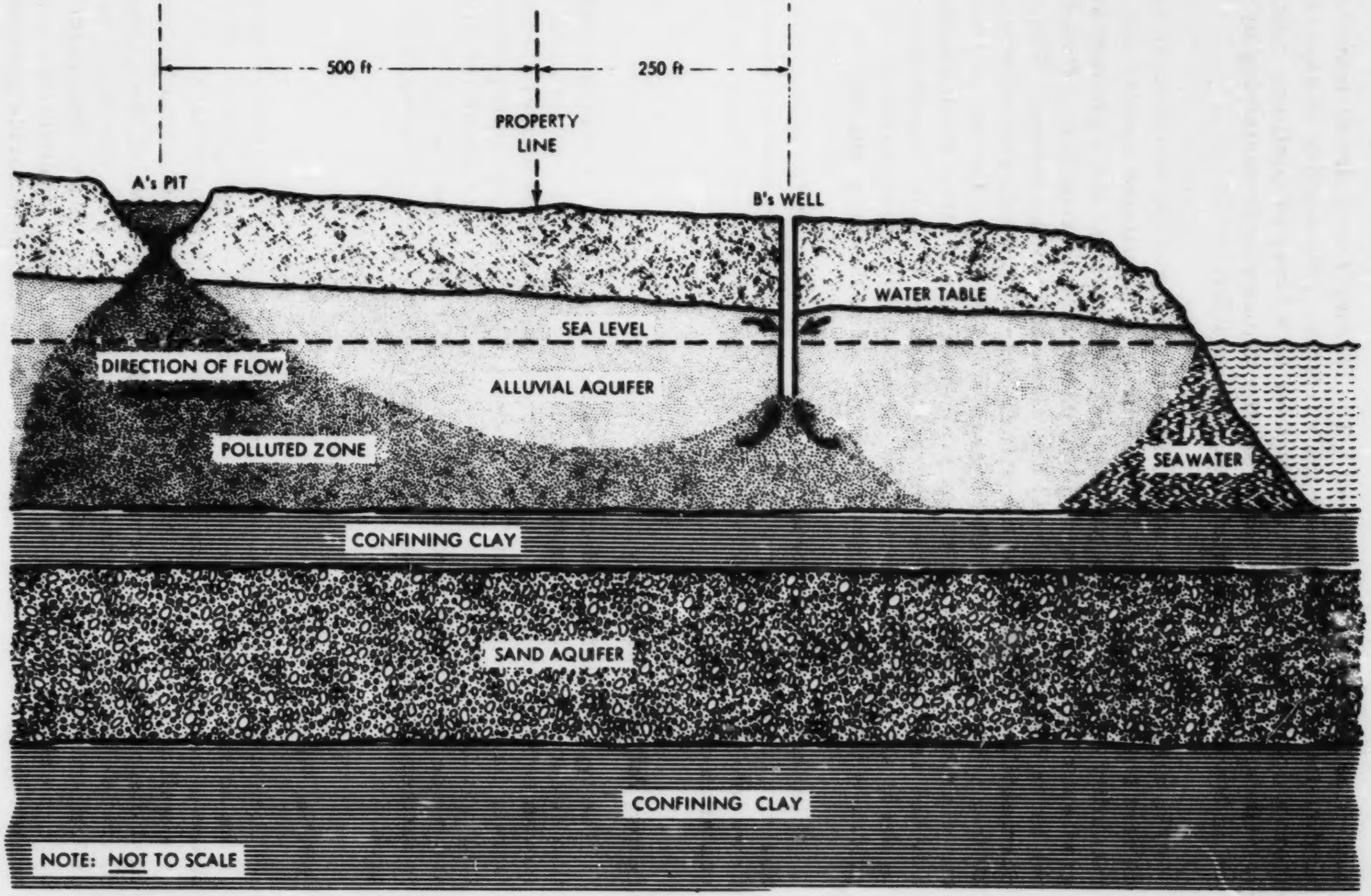
500 ft
250 ft
PROPERTY LINE
A's PIT
B's WELL
WATER TABLE
SEA LEVEL
DIRECTION OF FLOW
ALLUVIAL AQUIFER
POLLUTED ZONE
SEAWATER
CONFINING CLAY
SAND AQUIFER
CONFINING CLAY
NOTE: NOT TO SCALE

Figure 2. Hydrogeology of case study: elevation.

activities but not to the farmer. The farmer's well draws from an unconfined alluvial aquifer near the surface. This aquifer is separated from a deeper unpolluted sand aquifer by a layer of confining clay. Thus, in principle, the farmer can avoid the damage he is sustaining by deepening his well into the unpolluted sand aquifer.

The alluvial aquifer is about 40 feet thick and the water table is about 10 feet below the surface of the ground. The polluted aquifer has a permeability of 1500 gallons per day per foot (gpd/ft) and a groundwater gradient of 1.4 feet per mile in an easterly direction (i.e., directly from the brine disposal pit and past the water well to the ocean). With this permeability and gradient the natural rate of groundwater flow is about 20 feet per year. It therefore takes about 38 years for the pollutants to travel from the brine pit to the irrigation well. Since groundwater generally has an extremely slow rate of movement the rate hypothesized here is not at all unusual. These slow rates of groundwater movement and pollutant transport complicate analysis of pollution problems.

Note that seawater intrusion represents a second possible pollution source and that the groundwater polluted by the disposal pit eventually flows into the sea, which is assumed to be a zero cost dump for the contaminated water.

Existing Pollution Information

The types of information required in an analysis of groundwater pollution situations include the type, source, distribution, concentration, and movement of pollutants. It is assumed, as indicated above, that the farmer has recently identified the type of pollutant by appropriate chemical testing, but that he is entirely ignorant of all the other information and hence not able to predict probable future damages to his crop. It is further assumed that the oil company is completely unaware of the problem.

Pollution Plume

The three-dimensional pollution plume changes shape over time due to the normal diffusion process occurring within the aquifer. For purposes of case specification the chloride concentration level at the farmer's well is of particular interest between the time when the pollution is first discovered by the farmer (t_0) and the time at which the plume configuration reaches a steady-state configuration (t_θ). The steady-state, or long-run equilibrium, position in the absence of any abatement activities, is shown in Figure 3. By time t_θ all of B's groundwater would be tainted by chlorides in excess of 500 mg/l and the chloride concentration at his well would be 5000 mg/l. Such levels of pollution are assumed to

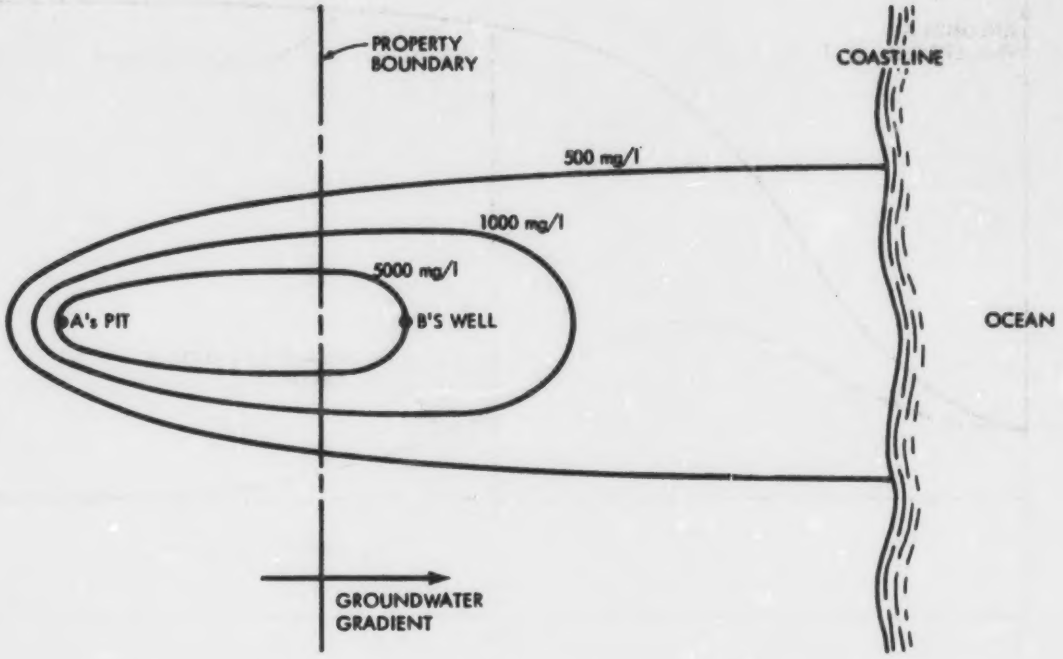

Figure 3. Hydrogeology of case study: plan.

be lethal to all feasible crops. The time-profile without abatement of the chloride concentration at B's well between t_0 and t_θ is shown by the solid curve labeled Cl_1 in Figure 4. If the polluting activity is abated completely at t_0 by some pollution control device such as pit-lining and relying on evaporation to dispose of the water, the time-profile of chloride concentration at B's well would be as shown by the dashed curve labeled Cl_2. When effective abatement is undertaken the chloride concentration gradually decays back to the ambient level as a result of dilution and flushing processes. Because of the slow rate of pollutant transport by groundwater, the time taken for the maximum chloride concentration to occur at the farmer's well if no corrective action is undertaken, or the time taken for the chloride concentration to return to the ambient level if effective abatement is undertaken, can both be considerable—easily 30 to 100 years. Because of these sizable time lags in the movement of polluted groundwater, one strong inference may be drawn immediately. If it pays at all, it will probably only pay to treat existing polluted groundwater at the point of use because abatement at the point of source may take decades, or even centuries, to have any impact. Consequently, with any reasonable discount factor, the present discounted value of the net benefits derived from source abatement will almost certainly be zero or negative.

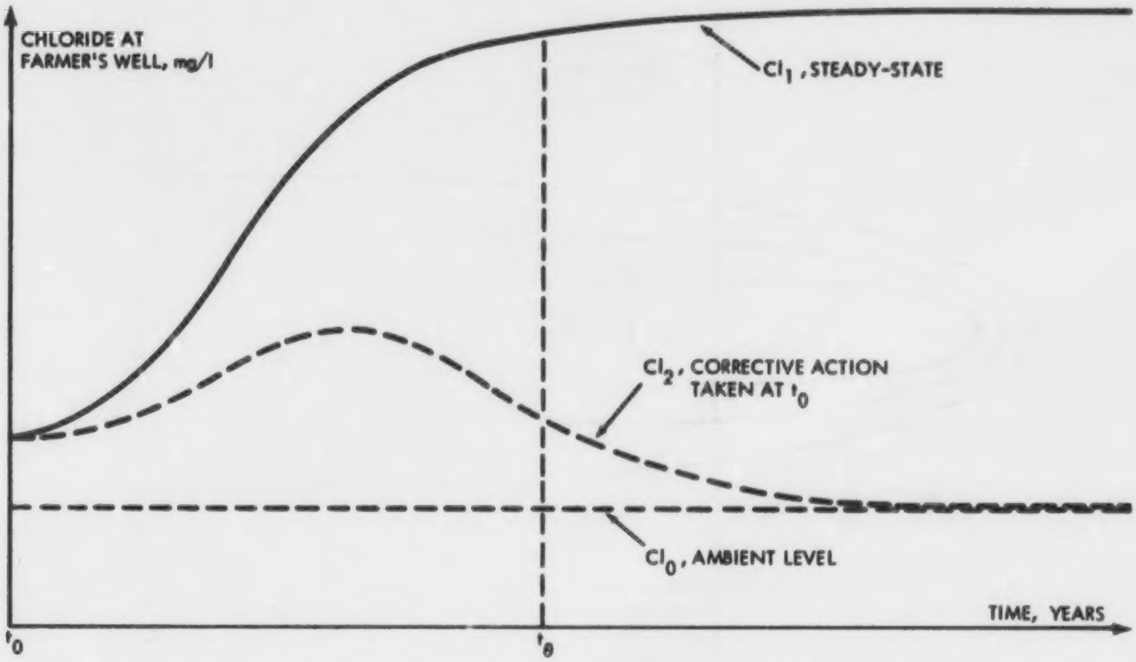

Figure 4. Alternative steady-state time profiles of chloride concentration.

ECONOMIC PRINCIPLES

Since the optimal allocation of resources to groundwater quality monitoring depends on the optimal level of aquifer quality and especially on the costs and benefits to society of deviations from that optimum level of aquifer quality, it is necessary to discuss how the optimal level of aquifer quality is, itself, determined.

The Damages (Cost) Functions

In the illustrative case the costs of pollution are incurred by the farmer in the form of crop damage; increases in brine pollution will first reduce rice crop yields and eventually force the farmer to employ his land in the production of irrigated crops with a lower net value. Ultimately, the brine pollution will force the farmer to cease irrigation from his well entirely and rely on natural precipitation, drill a new well, import water, etc. The total damage (D_b) to the farmer ($\underline{B}$) attributable to the oil company ($\underline{A}$) pollution of his well can be represented as follows:

$$D_b = N \int_{t=0}^{t=\infty} \left\{ H - K[Cl(t)] \right\} e^{-rt} \, dt \qquad (1)$$

where

N	is the number of acres under cultivation
t	is the time period (years)
H	is the net annual dollar return from an acre when employed in its highest valued use and the farmer's well is not polluted*
$K[\mathrm{Cl}(t)]$	is the net annual dollar return to an acre of land when employed in its highest valued use, given that $\mathrm{Cl}(t)$ is the average chloride concentration at the farmer's well during time t
r	is the discount rate.

In words, the damage per acre at time (t) is the difference between the net annual return from the land in its highest valued use given no pollution (H) minus the value of the net annual return from the best crop that can be grown given the chloride concentration at time (t), $K[\mathrm{Cl}(t)]$. The magnitude of this net loss per acre is then discounted into present value terms by the discount factor (e^{-rt}) summed over all time periods (here assumed to be infinity) and multiplied by N, the number of acres under cultivation. The result is the total loss (D_b) incurred by the farmer due to the pollution activities of the oil company.

The variable $K[\mathrm{Cl}(t)]$, i.e., the net annual dollar returns to an acre when employed in its highest valued use, given that the average chloride concentration in the farmer's well during t is Cl, will decrease as Cl increases. There are two basic ways for this to occur. First, as Cl increases either the yields of the farmer's rice crops will decline or he will be forced to substitute crops with a lower market value; either alternative means that $K[\mathrm{Cl}(t)]$ will decrease as $\mathrm{Cl}(t)$ increases. Second, the farmer can continue to grow rice crops and maintain their yields by drilling a new well, importing water, desalinizing his existing well, etc. Each of these alternatives, however, will increase his costs, and consequently $K[\mathrm{Cl}(t)]$ will still decrease as Cl increases.

Assuming that the farmer wishes to maximize the present value of his farm, he will always minimize the damage that a given chloride concentration in his well would cause him. He could do this by substituting crops, importing water, or some other best (least costly) available alternative. Thus, the farmer's self-interest dictates that he take that combination of avoidance and abatement actions which minimizes the sum of his avoidance, abatement, and damage costs.

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*Conceivably H could also be made a function of t by forecasting future changes in land use and commodity prices but this would require many additional assumptions and projections and is independent of the main problem at hand.

The total damages sustained by the farmer for various chloride concentrations at his well are plotted in Figure 5. These increase at an increasing rate as the chloride concentration increases because increases in chloride concentration levels when those levels are still low will merely cause crop yields to decline slightly while subsequent increases at higher concentration levels will require high cost responses such as drilling a new well, importing water, etc. Thus, the farmer's marginal damage curve as a function of various chloride concentrations at his well will also slope upwards as shown in Figure 6. Neither total nor marginal damages is sustained, however, until a certain minimum threshold concentration of chlorides at the farmer's well is reached.

Most of the variables and parameters in Equation 1, from which the total and marginal damages sustained by the farmer are calculated, would not be known to either the farmer or the oil company when the farmer's well becomes polluted. Their discovery would require appropriate monitoring, groundwater quality modeling, and other information collection.

The Benefits Functions

While the farmer sustains damages as a result of the oil company's polluting activity, the oil company derives an advantage, or benefit, from engaging in that activity.

The oil company is assumed to conduct its operations so as to maximize its present discounted value (G_a) where

$$G_a = \int_{t=0}^{t=\infty} [R(t) - C(t)]\, e^{-rt}\, dt \qquad (2)$$

and R(t) is the revenue obtained in time period t while C(t) is the internal costs it incurs in that time period (i.e., exclusive of any external costs it is imposing on the farmer). In maximizing its present discounted value, the oil company is generating, however, a certain concentration of chlorides at the farmer's well. This concentration is labeled R (not to be confused with R(t) — the oil company's revenues) in Figure 7. The chloride concentration at the farmer's well can be reduced below R by placing controls on the oil company's activities. It could, for example, line its brine disposal pit with a nonporous material, deep-inject its

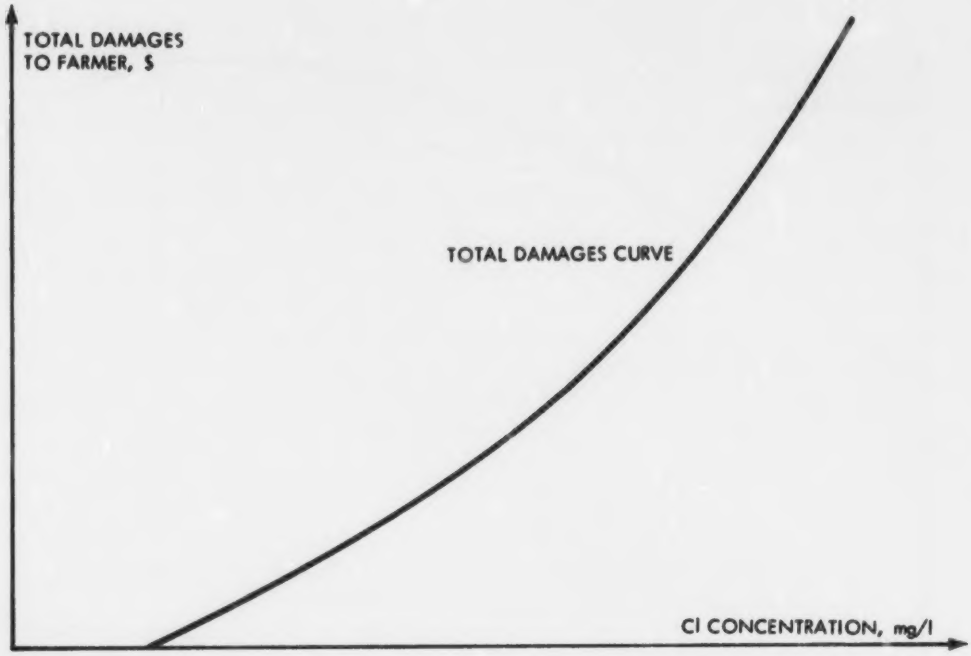

Figure 5. Farmer's total damages function.

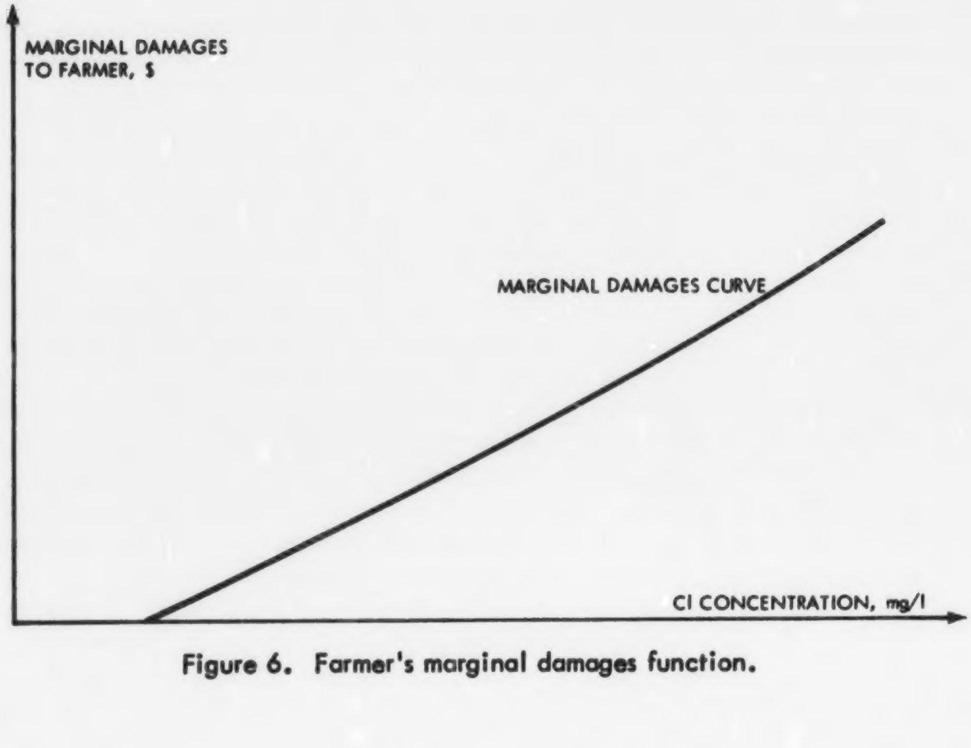

Figure 6. Farmer's marginal damages function.

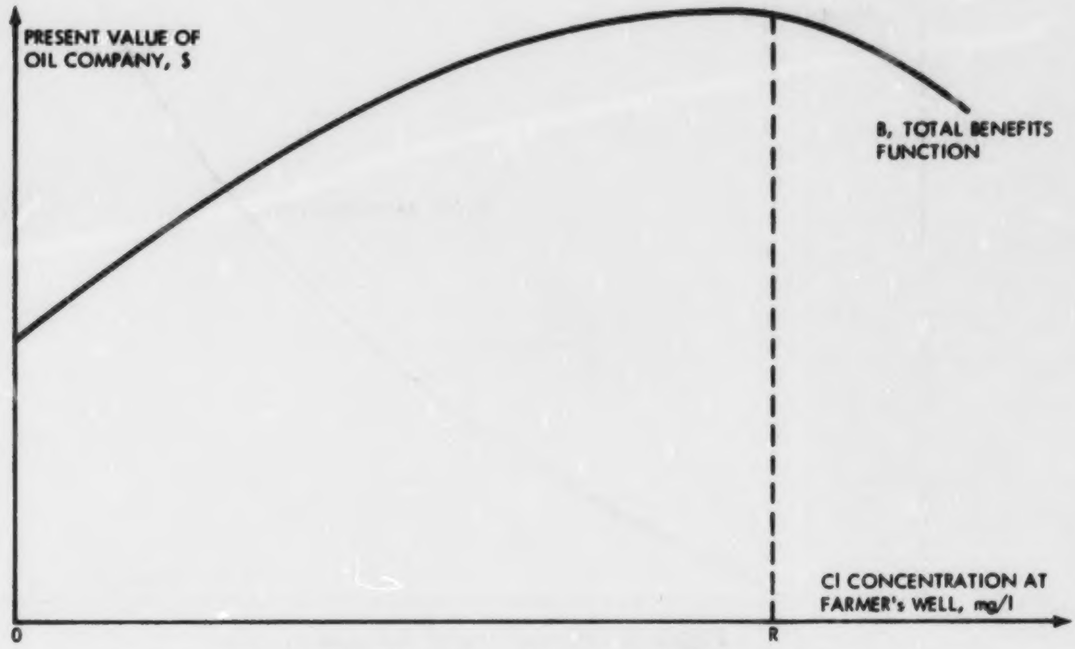

Figure 7. Oil company's total benefits function.

brine, or reduce the scale of its oil pumping operations. In any event, reducing the chloride concentration at the farmer's well will increase the oil company's costs or, possibly, decrease its revenues. In either case, as shown in Figure 7, the company's present value will decrease as the chloride concentration it generates at the farmer's well decreases. Since the oil company is still assumed to maximize its present value subject to the controls placed on it, the oil company will achieve any given level of pollution at the farmer's well in the least-cost, most efficient way. If the cost increases for successive unit increments of pollution reduction, as is likely, the oil company's present value curve as a function of the pollution it generates at the farmer's well will be shaped as shown in Figure 7. If it is very costly for the oil company to reduce the pollution it generates to low levels, in principle there is no reason why the total benefits curve should not intersect the horizontal axis rather than, as shown, the vertical axis. The associated marginal benefits curve is illustrated in Figure 8. When the oil company takes no account of the pollution it generates, it will generate pollution until the marginal benefit it derives from increasing pollution has fallen to zero.

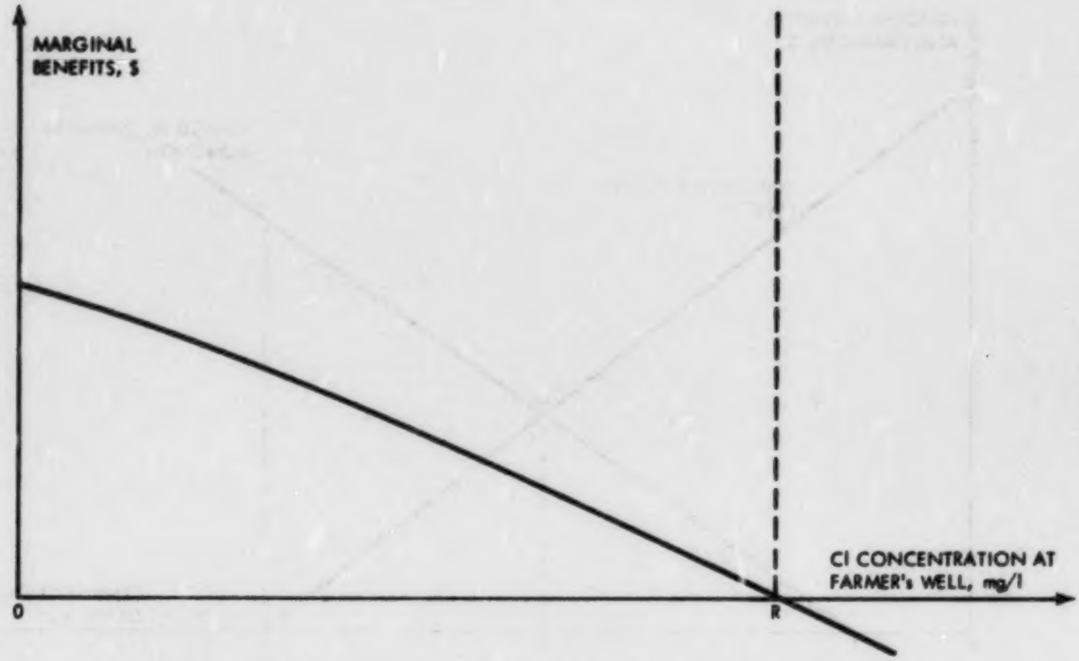

Figure 8. Oil company's marginal benefits function.

The Efficient Solution

The marginal benefits to the oil company and the marginal damages to the farmer associated with the oil company generating various different steady-state pollution concentrations at the farmer's well are combined in Figure 9. Assuming that resources are efficiently allocated when society's collective wealth is maximized, and ignoring the distribution of wealth, the optimal level of pollution at the farmer's well would be 0S, where marginal benefits and marginal damages are equal. This is equivalent to maximizing the net wealth of the oil company and the farmer who jointly comprise "society" for the purposes of this analysis. 0S is the optimal level of pollution because any increase in pollution beyond that level would impose greater additional damages on the farmer than it would generate additional benefits to the oil company, and any decrease in pollution below 0S would decrease the benefit to the oil company by more than it would decrease the damages to the farmer. Since the current level of pollution (0R) exceeds the optimal level of pollution (0S) then pollution is excessive. If pollution is reduced from 0R to 0S, the gain to the farmer in terms of damage avoided is equal to area A plus B while the loss

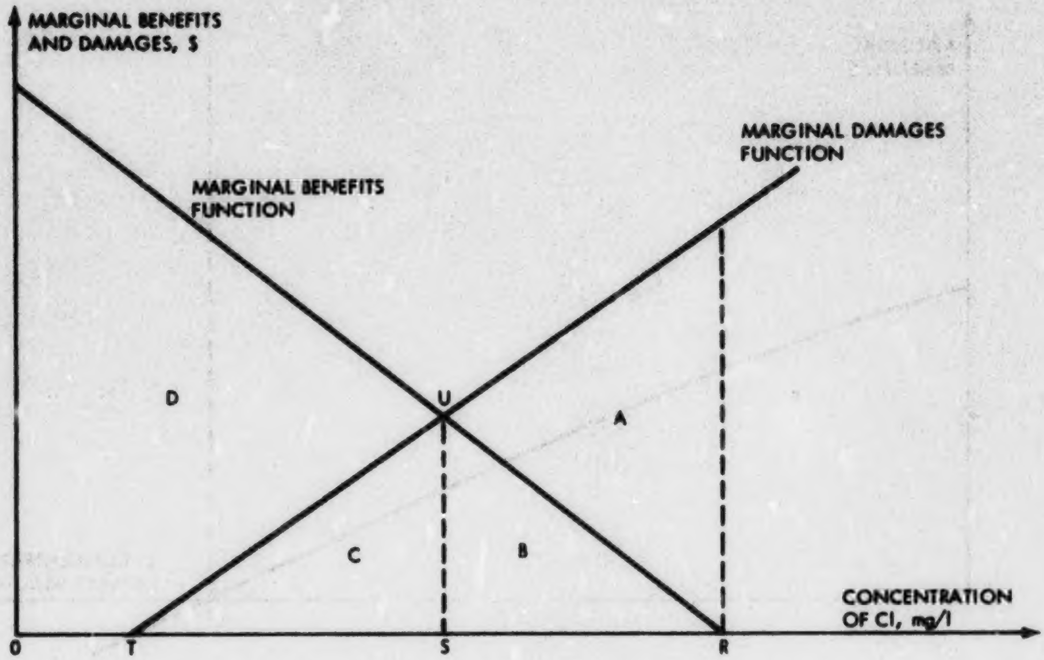

Figure 9. The efficient solution.

to the oil company in terms of benefits foregone is area B. Thus, the net gain to society would be (A + B) - B = A. The area under the marginal curve between any two chloride concentration levels (i. e., the integral) is equal to the difference in the total damages and benefits (which corresponds to that particular marginal) between those same chloride concentration levels.

Achieving the Efficient Solution

Whether the efficient level of pollution (0S) could be achieved by the farmer and the oil company negotiating a voluntary agreement depends on two factors: (1) whether or not the two parties have well-defined property rights in the groundwater underlying their land, and (2) their costs of transacting an agreement. The transactions costs associated with negotiating an agreement are of two types. First, there are contract negotiation costs proper. These include a variety of costs such as discovering the extent of the harm or benefit which is going to be done as well as how much harm or benefit is to be exchanged. This can be defined as monitoring for information in order to discover the extent of the harm or benefit. Second, there are costs for policing property rights because once an agreement is reached, the parties must monitor the groundwater for compliance, i. e., keep track of what pollutants are being emitted and in what quantities, to ensure that the agreed upon amount of harm or benefit is exchanged. These information and compliance monitoring costs are perhaps the most important component of transaction costs.

To illustrate the influence exerted by these two factors on whether or not the optimum level of pollution will be achieved requires examination of the case study using different specifications for property rights and transaction costs. Assume that (1) both the oil company and the farmer have well-established property rights in their groundwater, (2) their costs of transacting an agreement are zero, and (3) they pursue a solution to the pollution problem by negotiation. These assumptions are, of course, unrealistic. Property rights to groundwater are often not well defined and the costs of transacting (monitoring) a groundwater pollution agreement would certainly not be zero. They can, however, be used to demonstrate that the oil company and the farmer would come to a negotiated agreement specifying 0S as the level of pollution.*

The argument runs as follows. The area under the marginal benefits curve (Figure 9), for a given level of pollution, represents the total gain to the oil company. Similarly, for a given level of pollution the area under the marginal damage curve represents the total damage incurred by the farmer. If there is no negotiation the oil company will operate so as to generate 0R because at that level it will maximize the value of its benefits in an amount equal to (B + C + D). However, at this level of pollution the damage to the farmer is (A + B + C). If the oil company reduces the pollution it generates to 0S the damage to the farmer will be reduced by (A + B). The farmer would, therefore, be prepared to pay up to that amount to reduce the pollution to 0S. At this lower level of pollution the loss to the oil company (in terms of gain foregone) would be B. Consequently, the company would be willing to cut back to 0S for payment of slightly more than B. Since the farmer is willing to pay up to (A + B) for a reduction to 0S, and the oil company would be willing to cut to this level for slightly more than B, the two parties will negotiate to cut the pollution generated by the oil company to this optimal level. The precise amount the farmer pays to the oil company in excess of the required minimum (B) depends on the respective negotiating abilities of the two parties. Pollution will not be reduced below 0S because at lower levels the damages avoided by the farmer would be less than the gain foregone by the oil company. Thus, the farmer's maximum offer for a further reduction in pollution would be rejected by the oil firm.

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*This solution through negotiation was first demonstrated by Coase (1960). See Turvey (1963) as well for another informative discussion.

Notwithstanding the existence of an externality, as long as the interacting parties are willing to negotiate and can do so without cost, intervention by the State is unnecessary to secure an optimum resource allocation. However, the outcome when the State does impose on the oil company a legal obligation to compensate the farmer for any damages it causes him happens to be precisely the same. The total gain to the oil company for being able to generate 0S pollution is (D + C), whereas the total damage to the farmer of 0S pollution is only C. Thus, if the oil company is legally liable to compensate the farmer, the company would be willing to pay up to D + C for the privilege of generating 0S pollution. The farmer, on the other hand, would be willing to accept just C. The precise payment in excess of the minimum payment necessary (C) would again depend on the negotiating skills of each party. The oil company will not pay to increase the level of pollution beyond 0S because the marginal damages inflicted on the farmer that the oil company would become liable for would exceed the marginal gains to the oil company.

The assignment of a legal duty to the oil company to compensate the farmer does not affect the outcome, but only the distribution of wealth. With no legal liability for the oil company to compensate the farmer, the farmer will pay the oil company up to (A + B) to reduce the pollution it generates from 0R to 0S; when the oil company does have a legal duty to compensate the farmer, the oil company will pay up to (D + C) to generate 0S pollution rather than no pollution.

Although the outcome under zero transactions costs is interesting to consider, it is not realistic because transactions costs are not zero. These costs may be quite substantial, not only because of legal fees and negotiating costs, but because of the limited state of present knowledge. In the present example the only information now known by the farmer is that his well is polluted with brine water. He does not know whether the cause is seawater intrusion, the polluting activity of the oil company, or some other cause, and neither party knows the shape of the damage function. Faced with these uncertainties, and the reality that the well is contaminated, the farmer must gather information to (1) determine the cause of such damages, and (2) determine the probable extent of such damages. To accomplish each task the farmer must gather information through some process of monitoring, modeling, and information collection—a process that is certain to be very costly. Once this preliminary information is collected the farmer can confront the oil company with a claim for estimated damages plus a cease and desist order. The probable result is a costly legal battle involving additional monitoring expenses to substantiate conflicting legal claims.

Since legal, negotiation, and monitoring costs may be substantial, transactions costs will not be zero. In such circumstances, the above conclusions cannot be guaranteed to hold and the solution when transactions costs are positive must be examined. Recall that the oil company is now generating pollution at the level 0R and the farmer is being damaged in an amount (A + B + C). The net gain to the farmer (and society) of reducing the pollution to 0S is equal to A. However, if the transactions costs to the farmer of arriving at such an agreement (T_B) exceeds A, he will not attempt to negotiate and in the absence of any further initiative on his part, the oil company will continue to pollute at level 0R. However, if there is an enforceable legal burden on the oil company, the farmer can be expected to take action by filing suit against the oil company for damages and an injunction. Obviously, the oil company will prefer to avoid the injunction and negotiate an agreement with the farmer to pollute at level 0S. However, if the transactions costs to the oil company of arriving at such an agreement (T_A) exceeds D, the firm will not attempt to negotiate and must therefore suffer the injunction.

Thus, if the oil company is liable for damages, the firm will generate zero pollution whenever the cost of reaching agreement (T_A) exceeds its net gain (D) from reaching the agreement; similarly, if the company is not liable for the damage it causes, it will generate 0R pollution whenever the farmer's cost of reaching agreement (T_B) exceeds his net gain (A) from reaching such an agreement. Hence, large transactions costs are likely to prevent negotiating the socially optimal level of pollution, and lead to an inefficient allocation of resources. When, however, these transactions costs do not exceed the potential net gain, an agreement will be reached to operate at 0S. If the oil company is liable its gain will be ($D - T_A$) instead of D, and if the company is not liable the farmer's gain will be ($A - T_B$) instead of A. In this situation, positive transactions costs do not change the optimal level of pollution from 0S—they simply reduce the gains which result from polluting at this level.

If transactions costs are large enough to cause a suboptimal level of pollution other than 0S, the situation may be remedied by government intervention. For example, government can induce a shift to the optimal level by imposing an effluent charge on the oil company, equal to SU per unit of pollution, or invoke other policies such as permits to achieve the same result. The effluent charge will induce the oil company to cut back its pollution from 0R to 0S because, for all levels of pollution greater than 0S, the marginal gain is less than the marginal cost per unit of pollution.

Thus, government has the power to induce an efficient allocation of resources. However, government must estimate the marginal gain and damage curves before it can know the optimum level of pollution and determine the appropriate charge, again involving a great deal of costly monitoring and modeling. The cost to government of ascertaining this information and enforcing the implementation of any such policy will probably be at least as large as it would be to the principals involved; there seems to be no a priori reason that government could reduce monitoring costs.

Two Limiting Cases

The analysis presented in this section so far has dealt with the general case. However, it is equally applicable to two limiting cases that are of practical interest. First, it is quite possible that the efficient solution is zero pollution. That is the result when the marginal damages function exceeds the marginal benefits function at all levels of pollution as in Figure 10. In practice, it is possible that such might be the situation where the polluter is emitting carcinogenic materials or heavy metals into a community's drinking water supply. Second, it is also possible that the efficient solution is to impose no standard at all. That is the implication if the marginal damage function is everywhere zero and thus

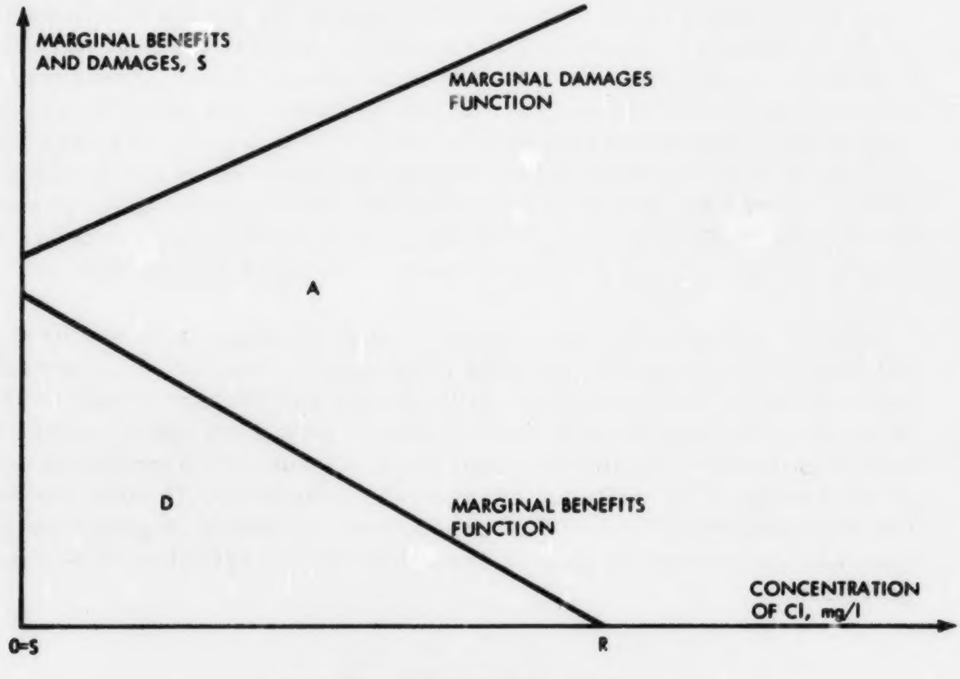

Figure 10. First limiting case.

contiguous with the horizontal axis as in Figure 11. In practice, it is possible that such might be the situation where previous pollution has already degraded the quality of an aquifer to such an extent that it is in effect a "sink" and, as a result, additional effluents will not produce additional damages.

With these principles concerning the establishment of the optimal level of groundwater quality as background, Section IV considers the issues specifically related to monitoring.

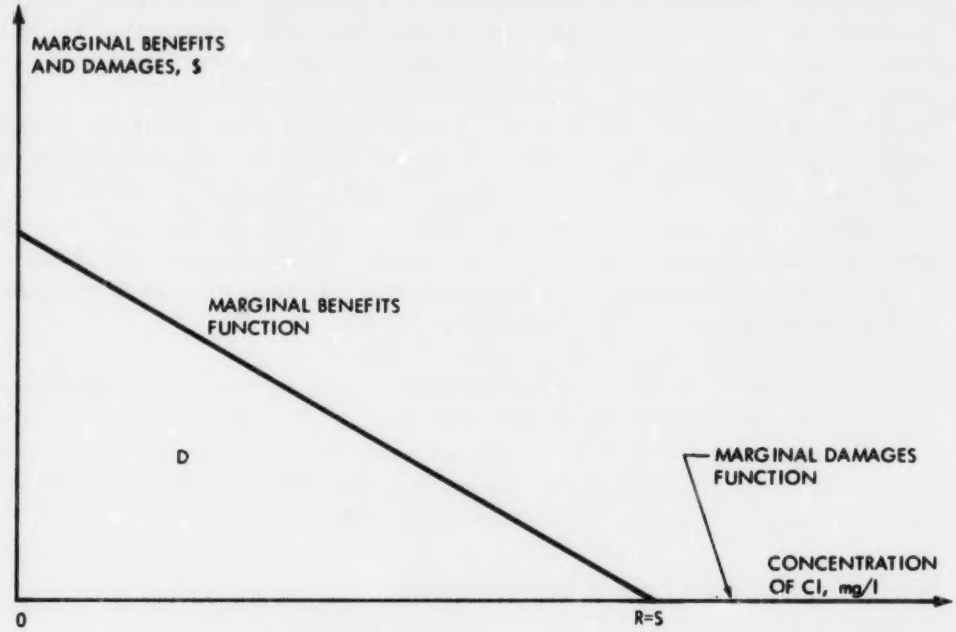

Figure 11. Second limiting case.

SECTION IV

MONITORING AND GROUNDWATER QUALITY STANDARDS

The primary purpose of this section is to analyze in the context of the framework developed in Section III the problem of selecting a preferred, or optimal, monitoring strategy under the assumption that the government intends to combat the excessive pollution of groundwater by (1) setting, and (2) enforcing groundwater quality standards by some form of direct regulations involving discharge licenses or permits, although a discharge license or permit procedure is not the only (or even necessarily the best) way in which groundwater quality standards can be attained. In principle, they can also be achieved by an effluent charges scheme or by paying subsidies for effluent reductions. The problem is analyzed in the context of a discharge licensing scheme because that is the option which has been adopted by EPA (USEPA, 1974).

A secondary purpose is to discuss important institutional considerations associated with implementing the preferred strategy selected, such as who should do the monitoring and who should pay for it. In general, these institutional considerations are embedded in the analytical discussion although some are discussed separately.

DEFINITIONS OF INFORMATION AND COMPLIANCE MONITORING

From an analytical point of view, it is convenient to divide monitoring into two components—monitoring for information and monitoring for compliance. In essence, monitoring for information is monitoring which is undertaken for the express purpose of estimating the marginal gain and, especially, the marginal damage function. Monitoring for this information is prerequisite to setting an optimal groundwater quality standard although groundwater quality standards may legitimately be set without any assurance that they are optimal for reasons that are explained subsequently.

Monitoring for compliance is that monitoring which is undertaken to insure that the groundwater quality standard that has been established is, in fact, adhered to. Since monitoring for information and monitoring for compliance are analytically distinct, they are discussed separately.

INFORMATION MONITORING

Information monitoring is designed to specify the damage function and inform policymakers of the damages which will be avoided if the standard is set at different levels.

The damage function (Equation 1) contains two terms; namely, H, the highest valued use of the farmer's land, and K[Cl(t)], the value of the farmer's land at time (t_0) given some time profile of the chloride concentration at his well over the period t_0 to t_∞. Since variable (H) is assumed to be known, only the determination of K[Cl(t)]is related to monitoring. To specify K[Cl(t)]it is necessary to (1) estimate the reduction in crop yields associated with different chloride concentrations and (2) estimate the chloride concentration profile through time for different pollution avoidance—abatement strategies. The function relating crop yields to chloride concentration levels is a problem in agronomics, not monitoring, so it need not be dealt with here. Of interest is the estimation of the chloride concentration profile through time for different pollution avoidance—abatement strategies which involves three activities: data collection, groundwater flow modeling, and monitoring proper.

The place to start will always be with the estimation of the chloride concentration profile in the absence of any pollution avoidance—abatement action—i. e., with the estimation of the solid curve labeled Cl_1 in Figure 4.

To predict Cl_1 (i. e., the time-profile of chloride concentrations at the farmer's well between discovery (t_0) and the steady state (t_θ) in the absence of any pollution abatement—avoidance steps being taken) it is essential to employ some form of groundwater quality modeling technique. In principle, this modeling process involves specifying the parameters of a simulation model which is then used to estimate the properties of the pollution plume over time. However, in practice, groundwater quality models vary from simple extrapolations based on experience and expertise to sophisticated computerized simulation models. Naturally, the degree of effort expended on the flow model will depend on the seriousness of the threat posed by the pollution situation, but any technique of quality modeling used will require input data. These data must either be collected from existing sources or obtained by monitoring. Apart from being a source of input data for the model, monitoring must also be employed to check the accuracy of the groundwater flow model. The sort of data that would have to be collected or generated in order to simulate Cl_1 with any degree of accuracy using a sophisticated groundwater quality model could include:*

- Data describing the geological column at both the oil company brine disposal pit and at the farmer's water well
- Brine pumping rates and brine concentration levels at the pit
- Net groundwater recharge and water table levels during the period in which the pit has been in existence
- Chloride concentration levels at the water well
- Past hydraulic head pressures
- Past rates of water withdrawal at the farmer's well
- The porosity, hydraulic conductivity, and saturated thickness of the aquifer
- The mass per unit volume of the solution in the aquifer under ambient conditions
- Relevant dispersion and diffusion coefficients
- Geographical data such as contour maps or simple topographical maps
- Statistics describing land use in the immediate vicinity.

To the extent that these data are not already available, it would be necessary to determine exactly what needed data are missing, how to procure them, and their acquisition cost. Since passage of PL 92-500 much of this information will be available at a lower cost than it would have been prior to the passage of that legislation because Sec. 308(a) states that "The Administrator . . . may at reasonable times have access to and copy any records." Thus, under the new law many of the data required are more easily accessible. In fact, prior to the passage of PL 92-500 the polluting agent almost certainly would have made information to which it was privy available only after legal proceedings had been implemented and the process of discovery instituted.

Having predicted Cl_1 through a process of data collection, modeling, and monitoring and, consequently, being able to estimate the level of damages associated with the oil company's activities in the absence of any abatement—avoidance actions, the next step would be to predict the time-profiles of chloride concentrations associated with different abatement—avoidance strategies using the groundwater flow model. The first obvious prediction would be that of Cl_2, the time-profile of chloride concentration at the farmer's well if a "perfect" abatement technique such as deep-injection of its brine is adopted by the oil company at t_0 (see Figure 4). Using this information, it would be possible to assess the damages which would be experienced by the farmer even though a perfect abatement technique were adopted immediately.

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*See Pinder (1973). In this article Pinder simulates the areal distribution through time of groundwater contaminated by cadmium originating at an aircraft plant on Long Island.

Analogously, other time-profiles of chloride concentrations at the farmer's well between Cl_1 and Cl_2 would have to be predicted using the groundwater quality model for less than perfect abatement—avoidance strategies to obtain a reasonably complete picture of the overall marginal damage function. However, the damages associated with Cl_1 (no abatement—avoidance) and Cl_2 (perfect abatement—avoidance) are most crucial. If the difference between these two damage estimates is greater than the cost of a perfect abatement—avoidance technique, then the perfect abatement—avoidance technique should be adopted because its cost would be less than the damages which would be avoided (if the marginal gain and marginal damage functions are not extreme). All other information concerning the marginal damage function would be redundant. This possibility corresponds to the first special case discussed at the end of Section III, where the marginal damage curve exceeds the marginal curve for all pollution levels. (As an aside, most discussions of pollution damage occur in this context. That is, pollution damages are estimated in terms of the existing level of pollution with the implication that these damages could be avoided by reducing pollution to zero. (See for example, U.S. Council on Environmental Quality (1971), Chapter 4.)

"Monitoring for information" is, then, an amalgam of data collection, quality modeling, and monitoring used to predict the properties of the pollution plume and estimate the damage function associated with the source of pollution.

Although groundwater quality modeling is in its infancy, the discipline is continuously advancing and such models are proving increasingly useful for making predictions, especially in situations involving point sources of pollution. However, as of now, such modeling is extremely costly because to be reliable it requires the procurement of a great deal of data and the services of highly skilled experts in the areas of hydrology, geology, programming, etc. Consequently, the possibility arises that the cost of acquiring the information on the damage function (M_i) may exceed the cost of the damages which can be avoided by having that information. This, of course, poses a real dilemma. However, through the accumulation of experience concerning recurrent pollution situations and reductions in the real cost of modeling that can be expected with the passage of time, such uncertainty can be expected to diminish.

The problems associated with the estimation of damage functions of groundwater pollution are not peculiar to that particular resource. Numerous references attest to the difficulty of obtaining damage functions for air pollution, ozone, and surface water discharges. See, for example, Barrett and Waddell (1973), pp vii, 4, 24, and 28; Blower (1973); Ridker (1967), p 153; and U.S. Council on Environmental Quality (1971), pp 107 and 135. These references illustrate an official, and semiofficial, awareness of the difficulty of estimating damage functions associated with other environmental resources analogous to the difficulty of estimating damage functions associated with groundwater pollution.

COMPLIANCE MONITORING

Permit Terms

This section assumes that the data collection, quality modeling, and information monitoring prerequisite to the estimation of the marginal benefits and marginal damage functions illustrated in Figure 9 have been accomplished and that the standard-setting authority has established an optimal level of pollution of 0S mg/l of Cl at the farmer's well. This level of pollution is associated with adoption of a given abatement technique by the oil company which, since 0S is positive, is not perfect. Some residual amount of chloride still finds its way into the groundwater at the source, and chloride concentration at the farmer's well is a physical relationship established through the groundwater quality model. Similarly, the model implies that if the residual percolation of brine at the source is, say, X gallons per year (gpy) and that this will generate 0S′mg/l of Cl at the farmer's well, it will also generate 0S′ mg/l at some point between the source and the farmer's well—for example, at the boundary of the oil company's property.

From this it follows that a discharge permit issued to the oil company that is designed to prevent violation of the 0S level of pollution at the farmer's well may have several dimensions. It may require that (1) the oil company initiate the appropriate abatement technique, (2) the oil company not allow more than X gpy of residual brine to percolate to the groundwater, and (3) the oil company not allow the chloride at its property line to exceed 0S′. In fact NPDES permits are frequently structured in this way. See, for example, Application for NPDES Permit to Discharge Treated Waste-Water to U.S. Waters, U.S. Environmental Protection Agency, Region IV Application No. AL 074 OYM 2 000570. When a permit is so structured, the permit dictates where monitoring may be undertaken in order to insure compliance with its terms. This may involve monitoring of all three of the restrictions listed above. If these permit terms are not violated, then presumably the optimal pollution level of 0S at the farmer's well is not violated either.

The Basic Principles

The example discussed in Section III illustrates the principles involved, the essential elements of which are shown in Figure 9 (see page 24). It will be recalled that if the oil company is not induced to recognise the harm done by the chloride emissions it generates, it will operate so that the chloride concentration its activities produce at the farmer's well is equal to 0R in Figure 9.

If a permitting agency issues a permit to the oil company to limit the chloride concentration level at the farmer's well to the optimal level of 0S by specifying given abatement techniques, each of those conditions imposed on the oil company implies an associated concentration limit at the farmer's well. If the oil company meets the standard, the gain to society is equal to area A minus the transactions costs (i. e., monitoring and other enforcement costs) that must be incurred in order to determine, and to obtain compliance with, the optimal standard 0S regardless of who does the monitoring. The cost to the oil company of compliance with the standard 0S is equal to B. Conversely, the gain to the oil company of noncompliance is B while the cost to society would be A + M, the transactions costs. (M might be zero if no effort were made to enforce compliance. However, M might be positive if some transactions (monitoring) costs are incurred but compliance is still not achieved.) In this case it is assumed that the permittee oil company will comply with the terms of its permit only if the expected cost of noncompliance exceeds the cost of compliance and will not comply if the expected cost of noncompliance is less than the cost of compliance, although it is recognized that not all permittees are entirely selfish and thus will not automatically violate the terms of their permits for economic reasons. The problem in such circumstances is analyzed subsequently in the subsection Permittee's Optimal Violation. It transpires that no substantive modification of the analysis is required.

The Expected Cost of a Standards Violation

This subsection treats criminal behavior as a rational reaction to the costs and benefits that the criminal subjectively estimates to be associated with his decisions, not as some form of social or psychological deviancy. It is in the vein, therefore, of the modern economic approach to criminal activity originally developed by Becker (1968 and 1974) and pursued by Stigler (1970) and Ehrlich (1973 and 1975).

The expected cost to a permittee of violating a standard is equal to

$$E(C) = P_d \cdot P_c \cdot E(F) \qquad (3)$$

where P_d is the probability of detecting violation of the standard. P_c is the probability of conviction for the violation, given its detection, and E(F) is the expected fine, given conviction. A few observations are in order. First, since E(C) is multiplicative in its arguments, if P_d, P_c, or E(F) is zero, then E(C) will be zero. A violation will therefore occur. Second, the arguments of Equation 3 can be traded off against each other. Any given expected cost level can be maintained by increasing one argument and appropriately decreasing another argument. Third, even if the probabilities of detection and conviction are one (unity), the expected cost of violating the standard could still be less than the expected gain from such a violation if the expected fine is small enough.

It is apparent that the EPA's water quality strategists are cognizant of this problem since they have stated that the "EPA considers the magnitudes of the fines that it intends applying as a major economic lever to assure compliance." (USEPA, 1974). Frequently in the past, it was cheaper to pay a small fine than to install and operate control equipment. Now PL 92-500 (Section 309(c)(1)) provides that "Any person who willfully or negligently violates . . . any permit condition or limitation . . . shall be punished by a fine of not less than $2500 nor more than $25,000 per day of violation . . . ."

Section 1423, (b)(2) of the Safe Drinking Water Act provides for similarly stiff penalties. "Any person who violates any requirement of an applicable underground injection control program to which he is subject . . . (A) shall be subject to a civil penalty of not more than $5,000 . . . or (B) if such violation is willful, such person may, . . . , be fined not more than $10,000 for each day of such violation."

Fines in the upper ranges of those allowed by PL 92-500 and PL 93-523 have the potential to make the expected cost of a standards violation high if the probabilities of detection and conviction are not trivially small. However, as reported, the EPA's administration of the Law has the effect of decreasing the severity of a fine. According to R. Johnson, Acting EPA Administrator for Enforcement, in a speech before the Practicing Law Institute on February 14, 1975, that appeared in the February 21, 1975, issue of Environmental Reporter, the EPA intends to follow generally a four-step approach in enforcing compliance schedules set forth in the National Pollution Discharge Elimination System permits. First, the EPA will telephone a discharger found to be in violation of the compliance schedule written into his permit. Next, EPA will send a letter to the discharger, and this will be followed by an administrative order if noncompliance persists. The final step, according to Johnson, would be court action; only in serious violations will EPA bypass these steps and go directly to court. Clearly, if this procedure is followed its de facto effect is to reduce any expected fine below the de jure level of fines. (Emphasis added.)

The probability of conviction (given detection) is treated as an exogenous variable in this report since to explore the reasons why detection of an offense sometimes does, and sometimes does not, lead to a conviction would be tributary to the main purpose of this report. For concreteness, and without loss of generality, the specific exogenous value given as P_c is assumed to be one (unity).

The Probability of Detection Function

The probability of being detected violating a groundwater quality standard is a function of the amount of compliance monitoring undertaken—as measured, say, by expenditure on compliance monitoring—and the severity of the violation. Thus, the probability of detection function is

$$P_d = f\,(M_c, V) \qquad (4)$$

where M_c is the expenditure on compliance monitoring and V is the size of the violation as measured by the difference between the actual level of pollution emitted and that allowed by the standard. In addition, it is assumed that

$$\frac{\partial P_d}{\partial M_c} > 0 \text{ and } \frac{\partial^2 P_d}{\partial M_c^2} < 0$$

while

$$\frac{\partial P_d}{\partial V} > 0 \text{ and } \frac{\partial^2 P_d}{\partial V^2} = 0 \ .$$

The positive first derivative with respect to M_c for this probability-of-detection function indicates that P_d increases monotonically with M_c while the negative second derivative indicates that it does so at a decreasing rate. This is based on the presumption of diminishing returns to monitoring. M_c might be zero if no effort were made to enforce compliance, or positive if some monitoring costs are incurred but compliance is still not achieved.

Graphically, P_d as a function of M_c would appear as in Figure 12. The curve increases monotonically and asymptotically approaches unity. The curve is drawn for a given size of violation. The solid curve labeled P_d is predicated on the assumption that the size of the violation is equal to V_1. If the size of the violation increased to V_2, then the whole curve would shift up to P_d' because the first derivative of P_d with respect to V is positive. Figure 12 also assumes that any given level of compliance

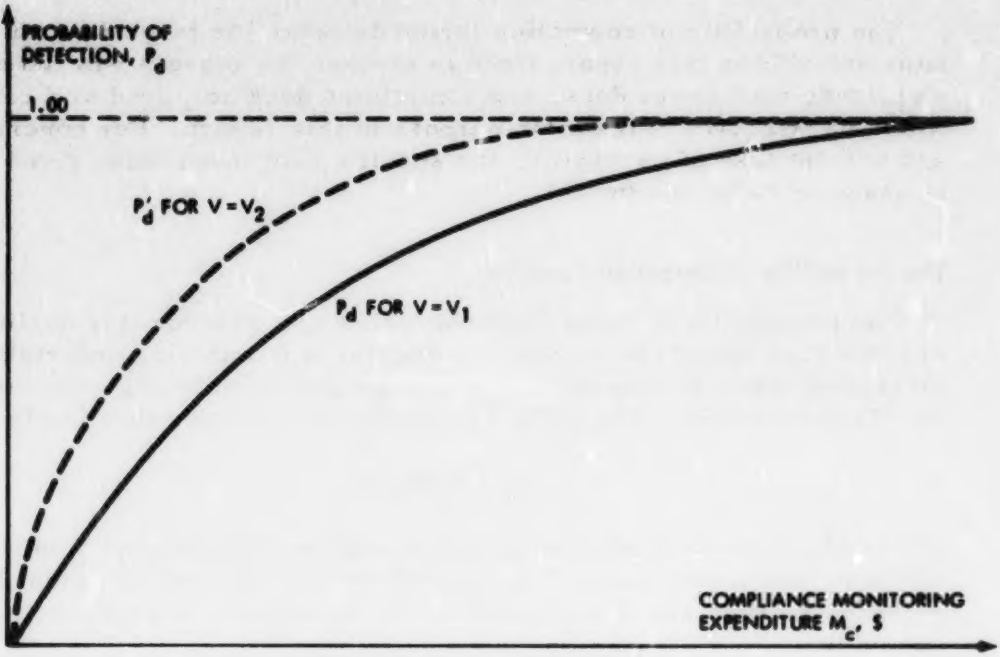

Figure 12. The probability of detection function.

monitoring expenditure which is undertaken is allocated over the monitoring techniques relevant to the pollution situation in such a way as to maximize the probability of detection for that level of expenditure. The principles governing this allocation are discussed in the following subsection.

The dependence of P_d on V can be clarified by reference to Figures 13 and 14. In Figure 13, if the permittee operated so as to generate a level of pollutants equal to 0U, he would be guilty of a violation of the standard by an amount of (0U-0S) = V. The gain to the permittee of such a marginal violation is equal to D_1.

Figure 14 can be used to explain that, for a given monitoring expenditure, the probability of detection of a violation of the standard will increase as the severity of the violation V increases (i. e., $\partial P_d / \partial V$ is positive). The figure illustrates a permittee with a point source of chloride pollution at P. The permittee is subject to a standard to the effect that the chloride concentration generated by his point source of pollution P must not exceed 300 mg/l anywhere outside the permittee's property line. The permitting authority has caused three monitoring wells to be sunk at A, B, and C after a study of the hydrogeological conditions surrounding P has led it to believe that the groundwater gradient is due east from P and, thus, that Well B will pick up the peak pollution measurement. In actual fact, however, the groundwater gradient is north of east and the peak

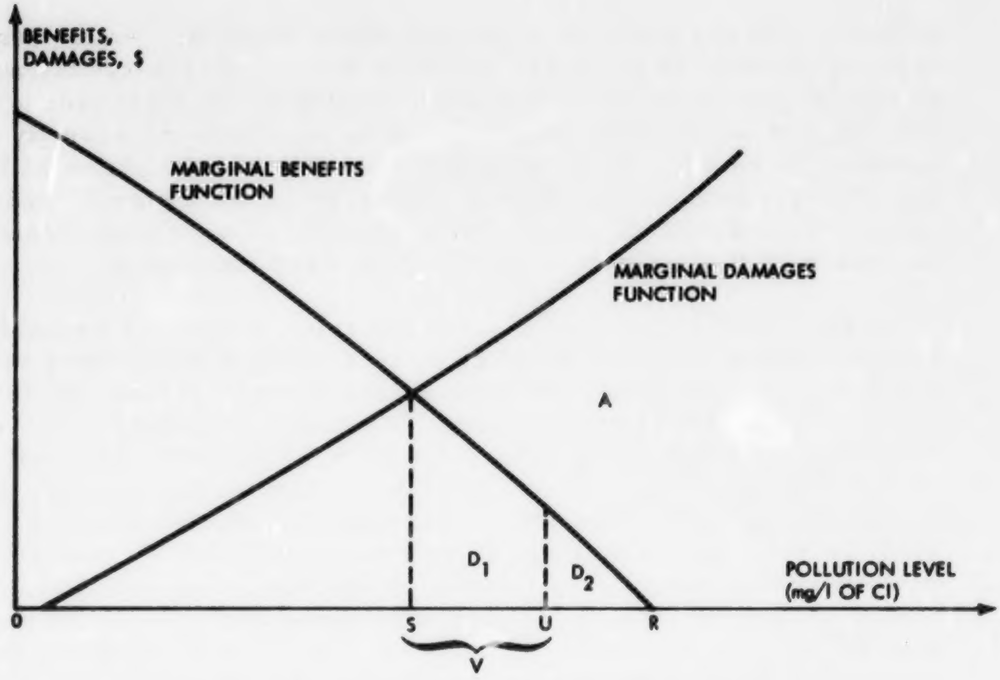

Figure 13. The gain from a standards violation.

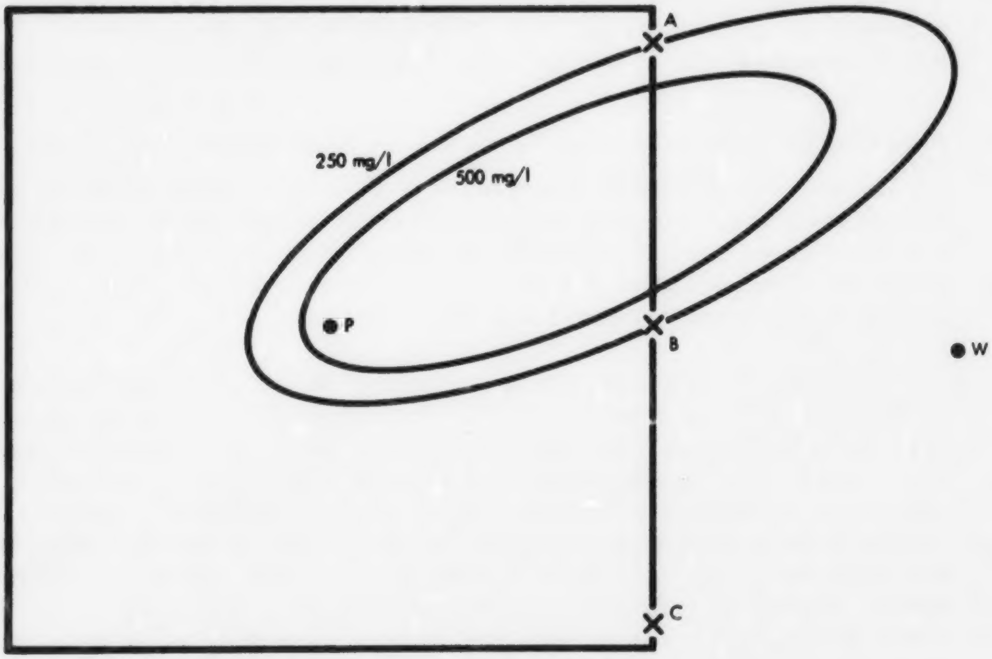
A
250 mg/l
500 mg/l
P
B
W
C

Figure 14. Detection and the size of the violation.

pollution part of the plume is between Wells A and B. Wells A and B are yielding readings of 250 mg/l, and thus do not indicate that the permittee is violating the standard with a concentration of 500 mg/l over a large area beyond his property boundary. If he increases the severity of his violation by emitting more pollutants from P, then the plume will expand, the 300 mg/l isopollution contour will arrive at Well A or B, and a violation will be detected. Thus, the probability of a violation being detected increases as the severity of the violation itself increases.

There seems to be no good reason to suppose that this probability of detection would increase at either an increasing or decreasing rate as the severity of the violation increases. Consequently, the second derivative, $\partial^2 P_d/\partial V^2$, is postulated to be zero. (Nothing substantive in the analysis which follows would be affected if the second derivative were either positive or negative. Only the indisputably positive first derivative is essential to the analysis.) Since the probability of detection would quite obviously be zero when V is zero, it may be inferred that the probability of detection will increase in proportion to the size of the violation. Graphically, therefore, when P_d is plotted as a function of V, it would appear like the solid curve shown in Figure 15, i.e., linear and emanating from the origin. The expenditure on monitoring is held constant at M_c^1. As long as the expenditure on monitoring is positive, the probability-of-detection function must eventually reach one (unity)—but, as illustrated, there is no guarantee that it will do so before V is equal to SR. If the expenditure on monitoring were increased to M_c^2, the curve would shift left to some position like that indicated by the dotted curve labeled T′.

Allocating Effort Among Alternative Monitoring Techniques

The preceding subsection discusses the probability of detecting a standards violation as a function of expenditures on compliance monitoring when the monitoring expenditures are allocated over the monitoring techniques relevant to the pollution situation in such a way as to maximize the probability of detection for that level of expenditure.

By definition, a "monitoring technique" is a monitoring method which is operationally relevant to a given groundwater pollution situation and also by definition, a "monitoring strategy" is a combination of monitoring techniques. For example, grab-sampling from monitoring wells and electrical conductivity measurements are two different types of monitoring techniques which, in principle, are relevant to the detection of chloride pollution of groundwater. Usually, any given monitoring technique can be applied with different levels of intensity. For example, 1 through n monitoring wells can be sampled at intervals of 1, ..., 7, ..., 365 days. Similarly, electrical conductivity measurements can be taken at

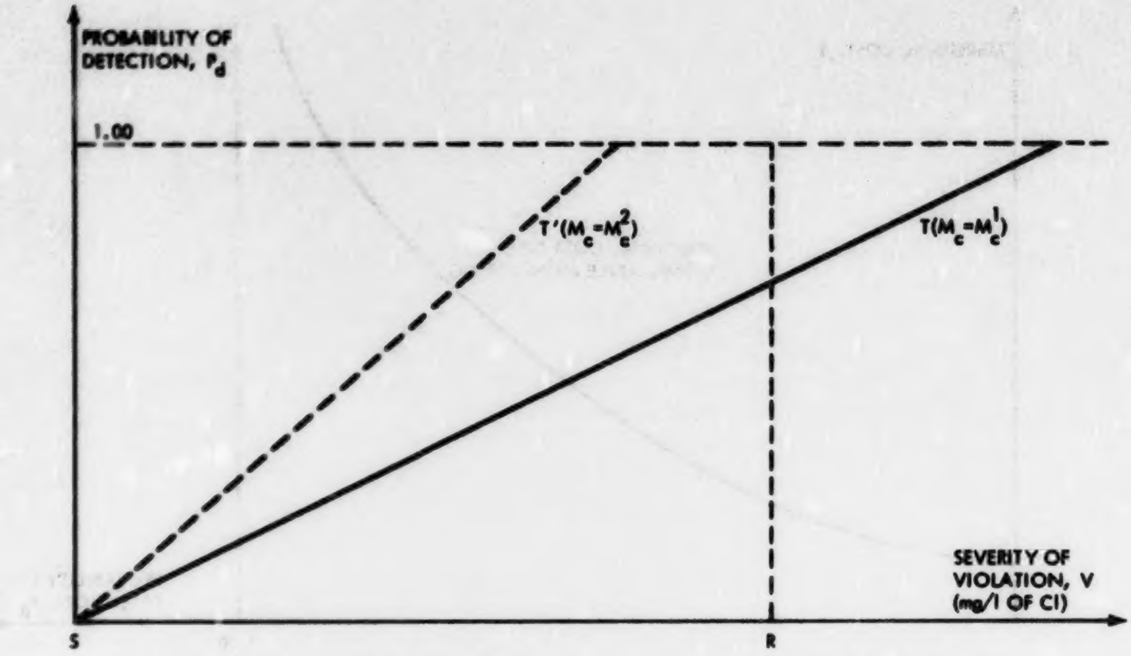

Figure 15. The probability of detection and the severity of the violation.

various locations and various frequencies. The feasible set of monitoring strategies consists of all possible combinations of monitoring techniques applied at all possible intensities.

Associated with each monitoring strategy within the feasible set of strategies is a certain probability of detection. The "output" of different quantities of compliance monitoring undertaken is different probabilities of detection. In order to maximize the probability of detection from a given monitoring budget, the efficient monitoring strategy to adopt is that associated with an allocation of the budget such that the increase in the probability of detection per dollar allocated to one monitoring technique is equal to the increase in the probability of detection per dollar allocated to any other feasible monitoring technique. (For any given probability of detection, following this rule will lead to a minimization of monitoring expenditures.)

If such a budget allocation is followed and there are diminishing returns to compliance monitoring, then the marginal cost of such monitoring as a function of the probability of detection will increase. Graphically, the marginal cost of monitoring as a function of the probability of detection will appear as in Figure 16.

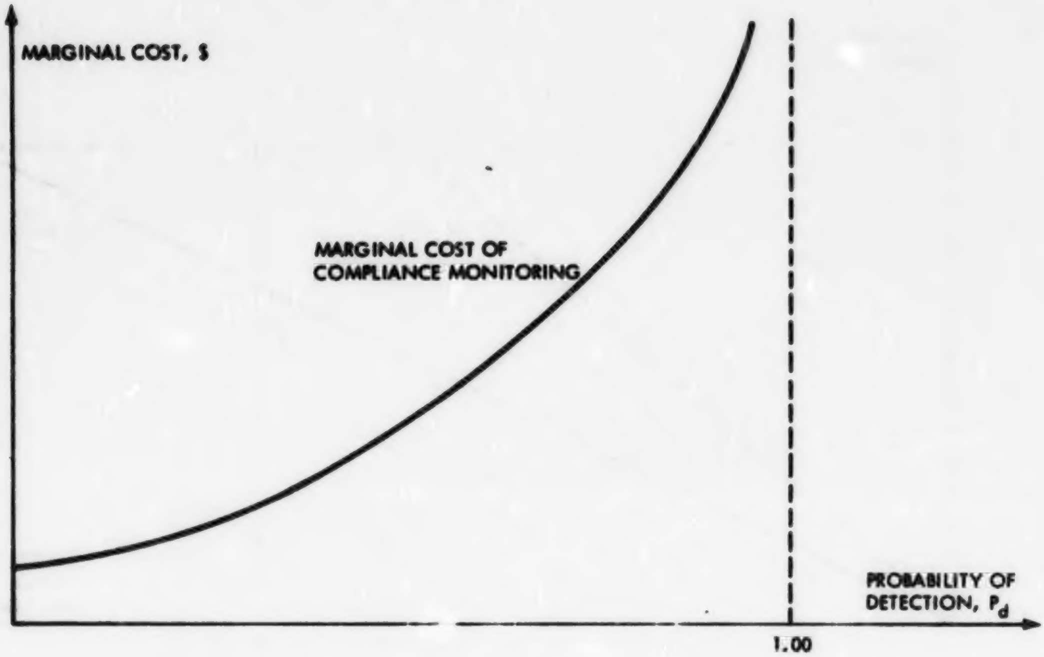

Figure 16. The marginal cost of compliance monitoring.

Implications of Independent versus Audited Self-Monitoring

The probability-of-detection function is independent of who does the monitoring, i.e., whether monitoring is done by some independent agency or whether self-monitoring subject to independent audit is the adopted practice.

By definition, independent monitoring is monitoring done by anyone but the permittee. Usually, it would be done by the permit issuing agency, but it could be delegated to some other body (except the permittee). Self-monitoring that is subject to audit is monitoring generally done by the permittee but where the permit-issuing agency reserves the right to conduct audit monitoring to ensure the integrity of the data collected. Both the Federal Water Pollution Control Act and the Safe Drinking Water Act envisage self-monitoring backed up by audit monitoring. For example, Section 308(a)(4) of PL 92-500 states:

> (A) The Administrator shall require the owner or operator of any point source to (i) establish and maintain such records, (ii) make such reports, (iii) install, use, and maintain such monitoring equipment or methods . . . , (iv) sample such effluents (in accordance with such methods, at such locations,

> at such intervals, and in such manner as the Administrator shall prescribe) . . . ; and (B) the Administrator . . . (i) shall have a right of entry to . . . any premises in which an effluent source is located. . . , and (ii) . . . have access to records, . . . monitoring equipment . . . , and sample any effluents . . .

Analogously, Section 1445 of the Safe Drinking Water Act states:

> (a) Every person who is a supplier of water . . . shall establish and maintain such records, make such reports, conduct such monitoring, and provide such information as the Administrator may reasonably require . . . (b)(1) . . . the Administrator . . . is authorized to enter any . . . property . . . [in order to audit] records, files, papers, processes, controls, and facilities . . .

The functional relationship between the probability of detection of a standards violation and the amount of monitoring undertaken when the party to be monitored does the basic monitoring, but is subject to audit, does not differ substantively from that of independent monitoring. This can be illustrated by the isopollution contour and monitoring well situation of Figure 14. The readings of wells A and B do not indicate to the permitting authority that a violation of the standard is occurring because a chloride concentration of 500 mg/l exists over a large area outside the permittee's property boundary. Clearly, the probability of this violation being detected would increase if additional expenditures on monitoring were incurred to sink more wells, especially between A and B.

If self-monitoring subject to audit is substituted in this situation, the permit-issuing agency would make as a condition of its permit issuance that the permittee himself sink wells at A, B, and C and report the results of samples taken therefrom to the agency. The integrity of their results would be preserved by the agency's random audit activities. However, once again, the standards violation which is occurring would not be detected by samples from A and B, and the probability of such detection would increase if the agency imposed on the permittee the obligation to sink more monitoring wells along its boundaries.

If the monitoring burden is placed on the permittee, the permit-issuing agency may be tempted to regard monitoring as a free good since it does not come out of its budget. This distinct possibility of a temptation to impose "over-monitoring" when self-monitoring subject to audit is the chosen modus operandi arises because of the incentive system inherent in the institutional structure of the situation. However, the objective of compliance monitoring should not, in general, be to maximize the probability of detecting a standards violation. To make this probability arbitrarily close to unity, monitoring wells would have to be sunk arbitrarily close together along the permittee's property line at great expense. Thus, the gain to society in enforcing the standard would, if the objective of maximizing the probability of detecting a standards violation were adopted, be dissipated in monitoring expenditure. If wealth maximization is society's goal, monitoring should be undertaken to ensure compliance with a standard only to the extent that the gain to society (which has, in terms of Figure 9, a maximum value of \$A) is in excess of the monitoring expenditures, (\$M) necessary to enforce compliance. However, the permit-issuing agency may perceive its function as maximizing the number of standards violations detected since these are immediately visible, whereas the more remote, but appropriate, goal of an overall improvement in society's welfare would not be so obvious. While some constraint would be imposed on the monitoring activities undertaken by the permit-issuing agency if they had to be financed from its own budget, no such constraint exists when they are financed by the permittee. This argument is not, of course, sufficient to justify independent monitoring to the exclusion of self-monitoring subject to audit because there are other reasons why the latter might be advocated. The most important of these is that self-monitoring subject to audit may be the least expensive per unit of monitoring.

Although it is not reasonable from society's point of view to equate the detection of a violation obtained by monitoring with the benefit of that monitoring program, others have erroneously done so. Ward and Vanderholm (1973), p 543, for example, state that "Figure 2 illustrates the relationship between effort expended [annual cost of monitoring] and benefits gained [percentage of spills detected] . . . ." Moreover, and highly significant given the above strictures, they continue, "the information presented [in Figure 2] answered the water-quality manager's question, how much effectiveness am I [sic] getting for my money."

Expected Fine Function

This section previously noted that PL 92-500 and PL 93-523 contain statutory scales of fines for water-quality violations. These scales of fines are exogenous variables whose upper bound is indicated in Figure 17 by F_{max}. However the expected fine is not an exogenous variable, but a function of the severity of the violation as is apparent from the remarks of Richard Johnson, Acting EPA Administrator for Enforcement. Therefore, the following expected fine function is postulated:

$$E(F) = j(V) \qquad (5)$$

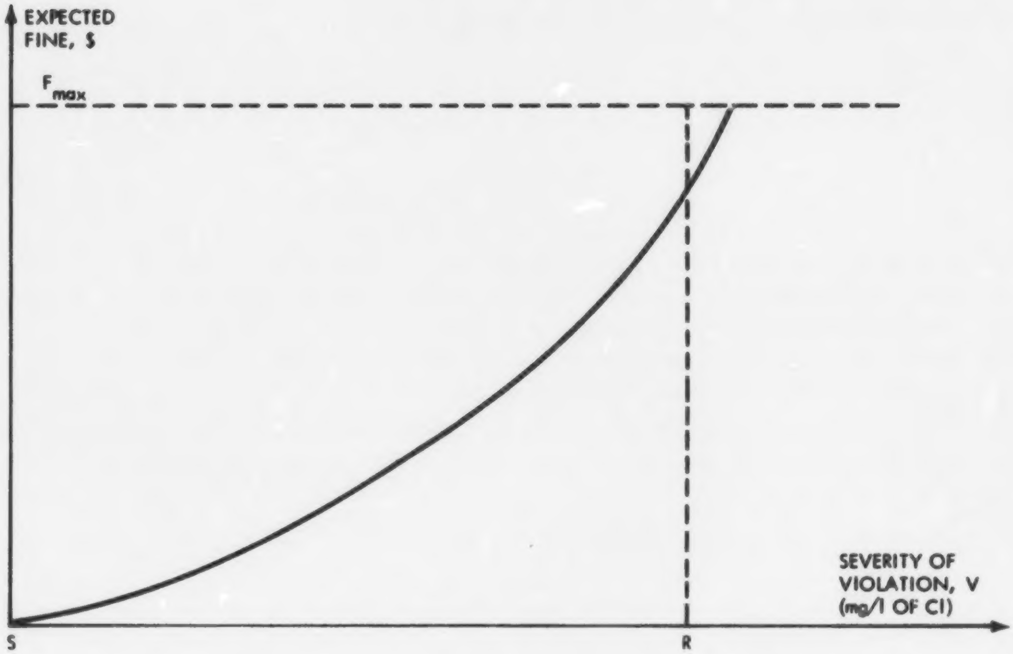

Figure 17. The expected fine and the severity of the violation.

with

$$\frac{\partial[E(F)]}{\partial V} > 0, \quad \frac{\partial^2[E(F)]}{\partial V^2} > 0 .$$

The signs of these derivatives are imposed to indicate what might be assumed to be plausible judicial attitudes; namely, that the size of the fine will be increased as the severity of the violation increases and at an increasing rate. (Less confidence can be placed in the sign asserted for the second derivative, but it is not crucial to the analysis.)

The expected fine as a function of the severity of the violation is illustrated graphically in Figure 17. The maximum violation that the permittee will perpetrate is SR. The courts may, or may not (as, in fact, illustrated), impose the maximum fine before this violation is reached.

Expected Cost of Violating a Standard, Compliance Monitoring Expenditures, and Size of Violation

By substituting Equations 4 and 5 into Equation 3 we find that:

$$\begin{aligned} E(C) &= f(M_c, V) \cdot P_c \cdot j(V) \qquad (6) \\ &= f(M_c, V) \cdot j(V) \end{aligned}$$

since the probability of conviction is assumed equal to unity. The function of Equation 6 relating the expected cost of violating a standard to the expenditure on monitoring for a given size violation (V) is simply a scalar transform of the function relating the probability of detection to the expenditure on monitoring (Figure 12). Thus, it will share the properties of increasing monotonically at a decreasing rate while asymptotically approaching the expected fine $(E(F_1))$ for that size violation. That is,

$$\frac{\partial E(C)}{\partial M_c} > 0 \text{ and } \frac{\partial^2 E(C)}{\partial M_c^2} < 0 \quad .$$

Such a function is illustrated by the solid curve in Figure 18. The broken curve indicates the situation if the size of the violation is larger.

The function relating the expected cost of violating a standard to the degree, or severity, of that violation (for a given level of expenditure on compliance monitoring) will emanate from the origin, be convex from below, and terminate at F_{max} (the maximum fine)—as shown by the solid curve in Figure 19. The shape of this curve is dictated by the shape of the function of Equation 5 since the probability of detection is assumed to be proportional to the size of the violation (see Figure 15). The broken curve in Figure 19 indicates the situation if the level of compliance monitoring undertaken was increased from, say, M_c^1 to M_c^2.

Permittee's Optimal Violation

The permittee's total benefits function with respect to the chloride concentrations imposed on the farmer's well is discussed in Section III and illustrated in Figure 7. That part of the total benefits function which exceeds 0S chloride concentrations (the standard) is shown in Figure 20. It increases monotonically between S and R where it reaches a maximum, which is the chloride level the permittee will generate if no attempt is made to regulate his activities. Thus, algebraically, the permittee's total benefit as a function of the size of his violation of the standard is given by

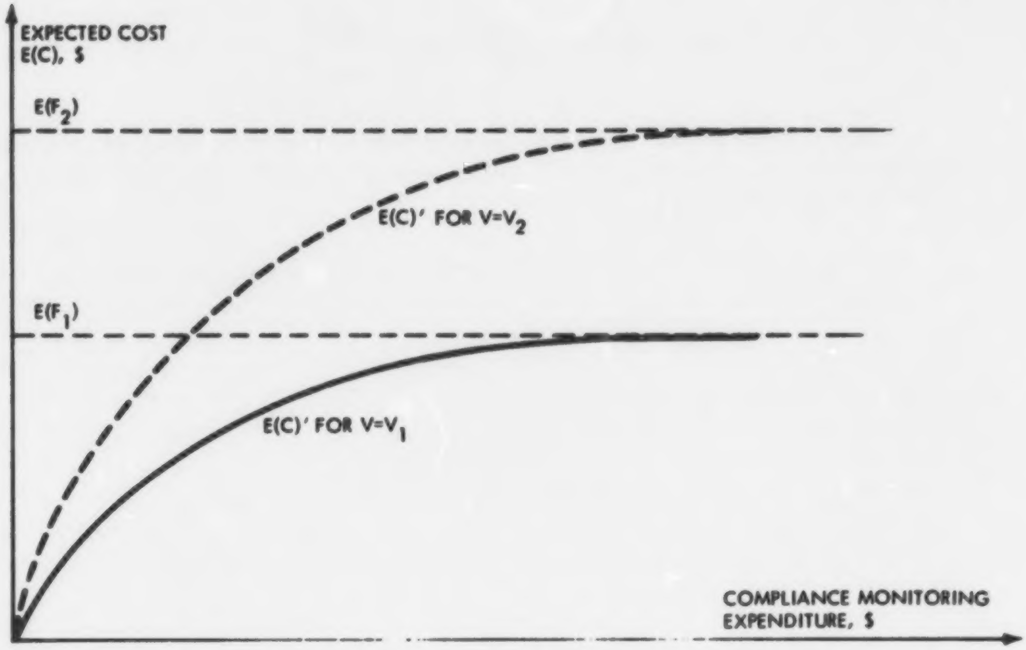

Figure 18. The expected fine and expenditure on compliance monitoring.

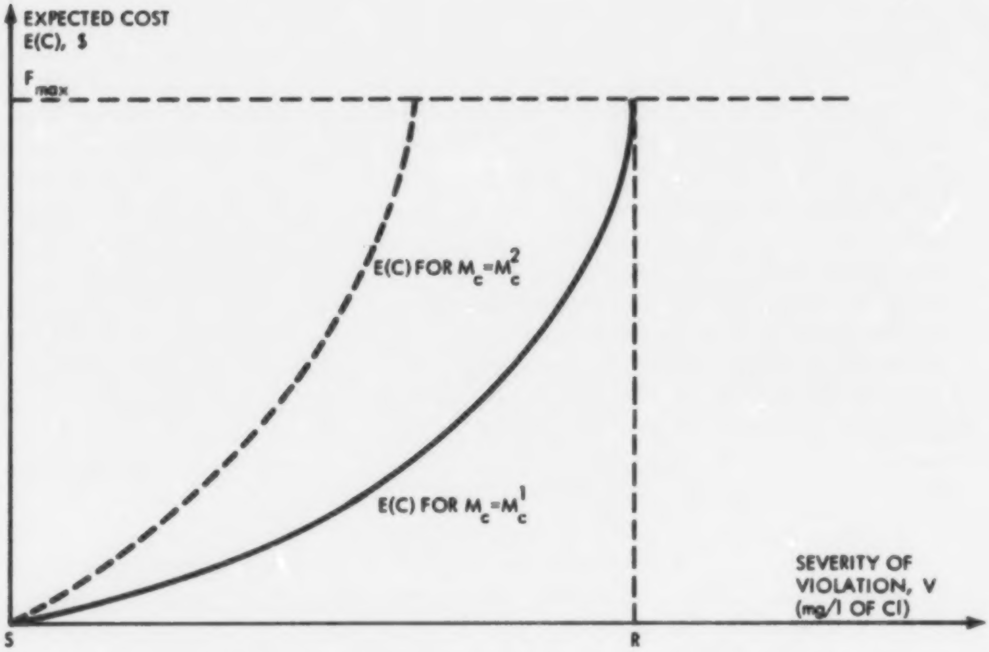

Figure 19. The expected cost and the severity of the violation.

$$B = g(V) \quad ; \quad \frac{\partial B}{\partial V} > 0 \ , \quad \frac{\partial^2 B}{\partial V^2} < 0 \ . \qquad (7)$$

Figure 20 also includes the permittee's expected cost as a function of the size of his violation for a given scale of fines and level of monitoring (taken from Figure 19).

The permittee's total benefit and expected cost functions can be used to establish the level of emissions that it is optimal for the permittee to generate and, therefore, the optimal severity of the standard violation for the permittee to undertake. The assumed objective is to choose V so as to maximize net expected gain (H) where H is defined to be the difference between total benefits and expected cost. That is, the permittee is to maximize $H = B - E(C)$. Diagrammatically, this occurs at V_1 where the slopes of the total benefit and expected cost curves are equal. Analytically, the maximum occurs when the marginal benefit from increasing the violation is equal to the marginal expected cost from increasing the violation.

Up to this point the analysis assumes that the sole objective of the permittee is to maximize the permittee's net expected gain (even though that involves illegal activities). On this basis V_1 in Figure 20 is the permittee's optimal violation in that it maximizes net expected gain after allowance is made for the expected cost of the standards violation. However, the permittee may also derive disutility from engaging in illegal activities (i.e., violating a legally promulgated groundwater quality standard), which introduces the consumption of nonpecuniary goods into the utility function. (This analytical innovation was pioneered by Becker (1957). In addition, see Williamson (1963 and 1964), and Alchian (1965).) Essentially, the permittee has indifference curves like those illustrated in Figure 21, which show a diminishing marginal rate of substitution between the net expected gain and illegal activities. U_3 is preferred to U_2 and U_2 to U_1 because for a given net expected gain equal to Π_1 a larger violation (V_2) must leave the permittee with a lower level of utility than a smaller violation (V_1). Analogously, for a given violation (V_2) a higher level of net expected gain (Π_2) must generate a higher level of utility for the manager than a smaller level of wealth (Π_1). Completely unscrupulous permittees would have horizontal indifference curves; completely scrupulous permittees would have vertical indifference curves.

The permittee's opportunity set under various conditions is illustrated in Figure 22. The XX curve illustrates the net expected gain from the permittee's activity as a function of the pollution generated when no groundwater quality standards must be met. Wealth is maximized at Π_1 where the level of pollution generated is R. The effect of the imposition of

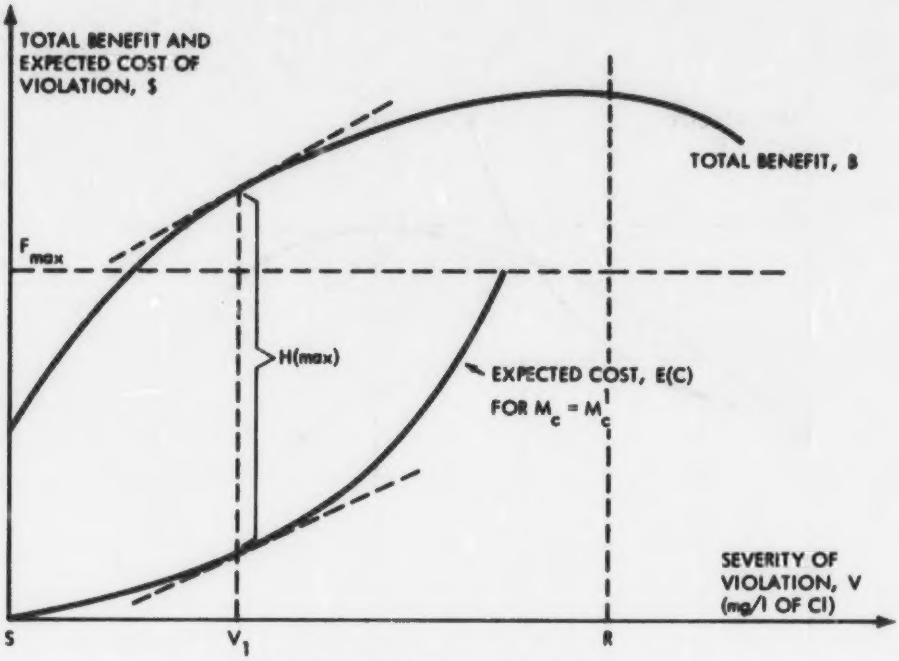
TOTAL BENEFIT AND EXPECTED COST OF VIOLATION, $
TOTAL BENEFIT, B
F_{max}
H(max)
EXPECTED COST, E(C) FOR $M_c = M_c'$
SEVERITY OF VIOLATION, V (mg/l OF Cl)
S
V_1
R

Figure 20. The optimum violation.

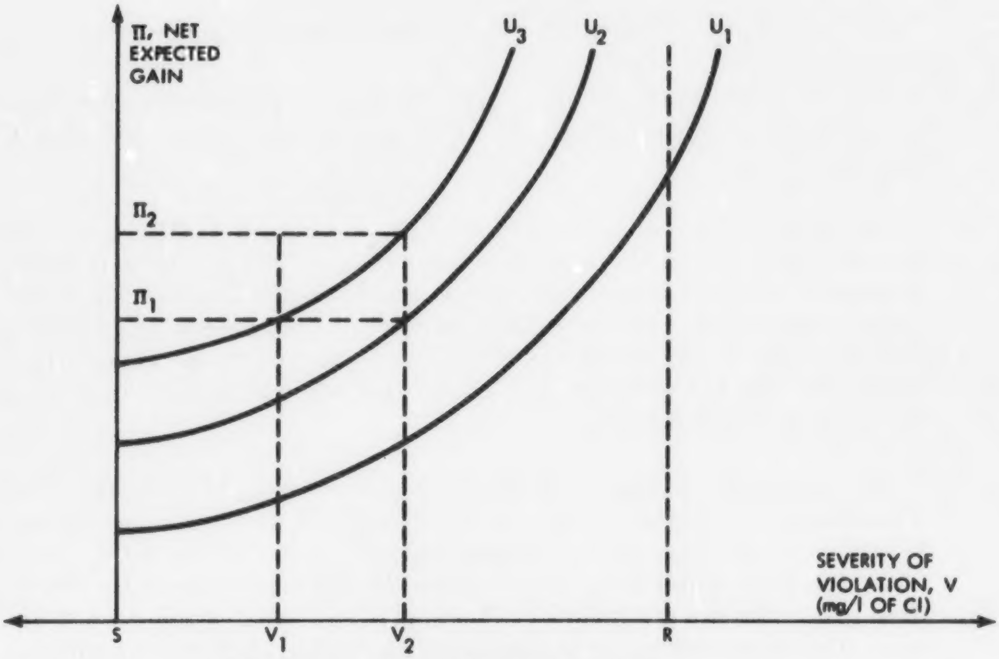
π, NET EXPECTED GAIN
U_3
U_2
U_1
π_2
π_1
SEVERITY OF VIOLATION, V (mg/l OF Cl)
S
V_1
V_2
R

Figure 21. The preference function.

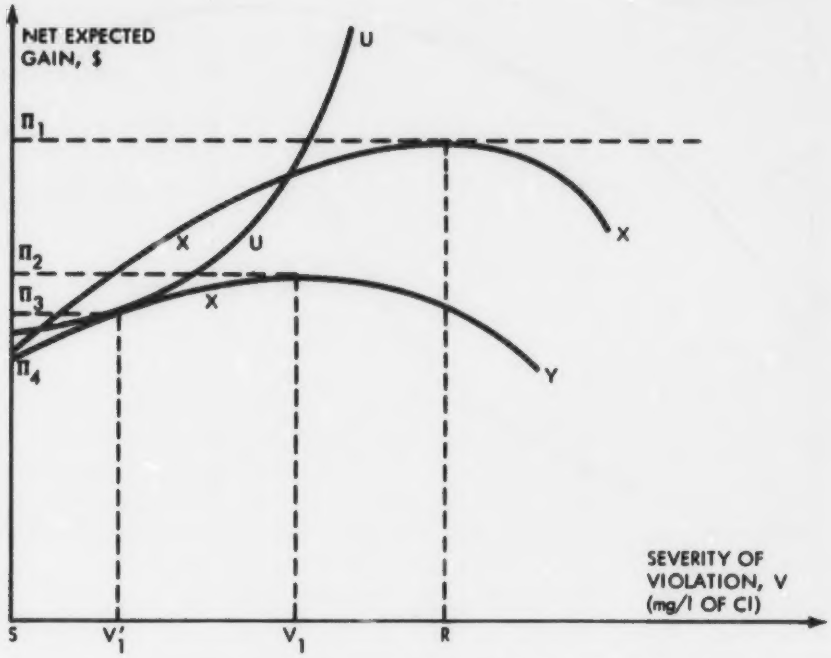

Figure 22. The revised optimum violation.

standards is to shift the net expected gain curve downwards everywhere to the right of the standard (S) as illustrated by curve XY with a maximum between S and R.

As long as illegal activities do not generate disutility, wealth is maximized at Π_2 where the violation undertaken is V_1. This is where XY is tangential to the highest horizontal indifference curve (not shown). As an aside, where the permittee is completely scrupulous the optimum violation is zero. This is where XY crosses the vertical axis. Here it intersects the highest indifference curve (not shown) at a corner solution. The net gain generated is Π_4.

If, however, illegal activities do generate disutility, the violation which maximizes permittee utility is V_1' where XY is tangential to the UU indifference curve. Since UU slopes upward from left to right, the optimum violation (V_1') when illegal activities do generate disutility must be less than the optimum violation (V_1) when illegal activities do not cause disutility. The substantive implication of recognizing that a permittee may derive disutility from engaging in illegal activities is minimal; the only effect is to reduce the size of the optimal violation. Since this makes no difference to a purely qualitative analysis such as this, the remainder of the analysis assumes for simplicity that a permittee does not derive any disutility from illegal activities.

Since the effect of additional compliance monitoring expenditure is to increase the slopes of the expected cost function, this would make the slopes of the permittee's total benefits and expected cost curves (see Figure 20) equal at a lower value of V. Consequently, the permittee's optimal violation will decrease as expenditure on compliance monitoring increases. If expenditure on compliance monitoring is increased sufficiently, the permittee's optimal violation will enventually become zero. This occurs when the slope of the permittee's expected cost curve exceeds that of his total benefits curve for all V —i. e., when the marginal benefit from a violation is less than the marginal expected cost for all violations. Although it is possible to reduce the permittee's violation to zero by increasing compliance monitoring expenditures, it may not be optimal from society's point of view to do so, depending on the social gains and losses associated with monitoring.

Optimal Compliance Monitoring Expenditure

The marginal cost of compliance monitoring is a function of the probability of detection (the "output" of compliance monitoring). The optimal expenditure on compliance monitoring will be that level of expenditure for which the marginal cost is equal to the marginal benefit derived. Since a permittee's optimal violation of a standard will decrease as the expenditure on compliance monitoring increases and vice versa, this allows establishment of the functional relationship between expenditure on compliance monitoring and the social gain from that expenditure.

The social gain from monitoring is defined to be the social loss avoided by that monitoring. To illustrate this, consider Figure 23. If no monitoring is undertaken, the expected cost to the permittee is zero and he will produce 0R pollutants at the farmer's well. In terms of Figure 20, the expected cost function is contiguous with the horizontal axis (i. e., zero) and thus the net expected gain (H) is maximized at T. The loss to society is equal to the area bounded by the marginal damage and benefit functions between S and R (amount A). If sufficient monitoring is undertaken to reduce the permittee's violation by one unit (to SR_1), the loss avoided is given by area (T_1). Analogously, if enough additional monitoring is undertaken to reduce the violation by one more unit (to SR_2), the total loss avoided is given by area ($T_1 + T_2$) and the marginal loss avoided by area (T_2). Thus the total loss avoided increases as the violation decreases and it does so at a diminishing rate towards a maximum equal to A (which occurs at zero violation—see Figure 24.)

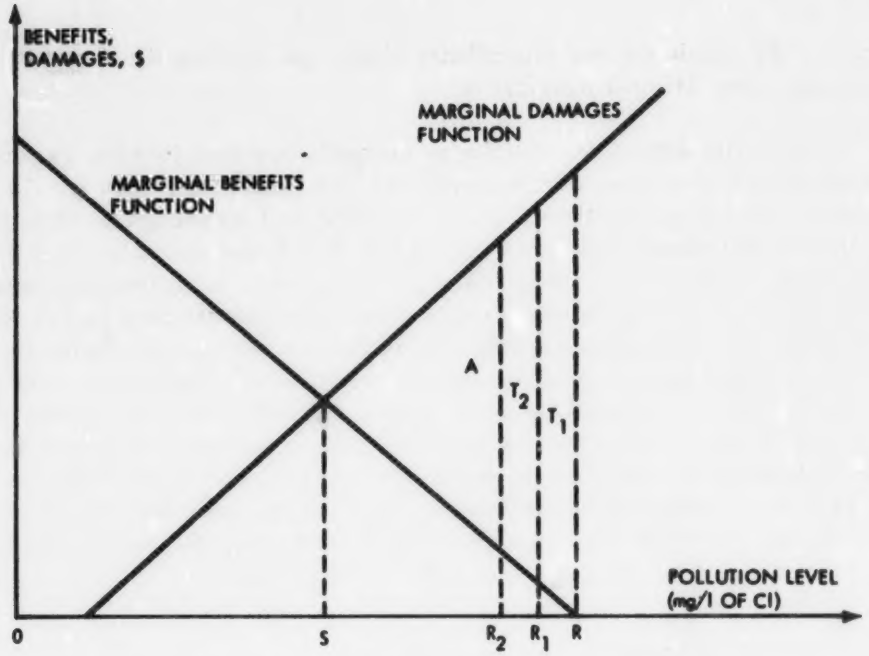

Figure 23. The benefits from violation reduction.

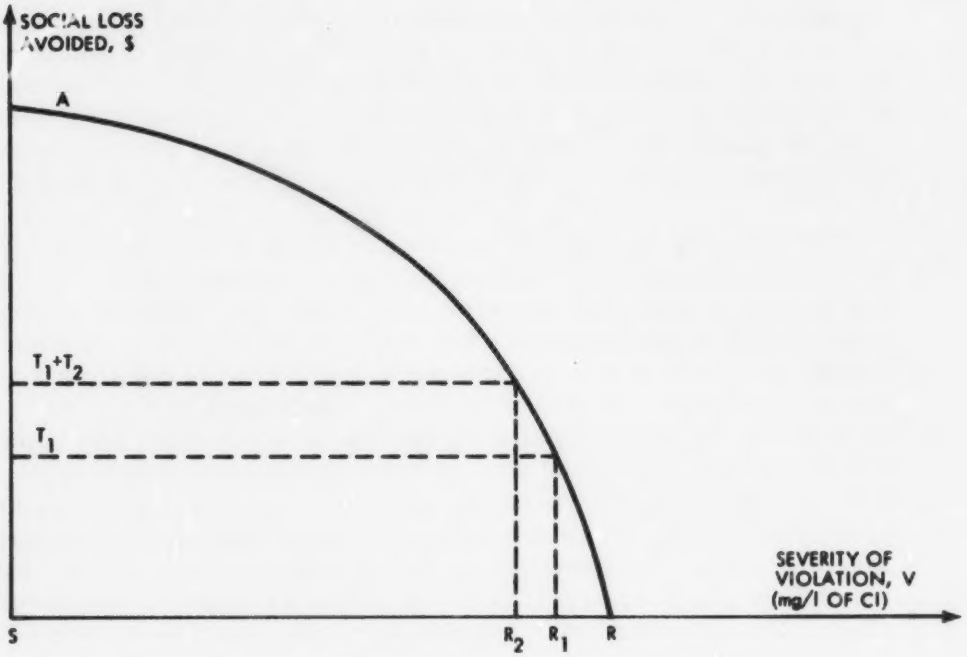

Figure 24. Diminishing returns to violation reduction.

The relationship between various levels of probability of a violation being detected and the total social loss avoided may be inferred from Figure 25. The upper left quadrant shows the relationship between the probability of detection and expenditure on monitoring. The lower left quadrant shows the expected cost of a violation to the violator as a function of the probability of detection—which, from Equation 1, is a proportional relationship. The lower right quadrant shows the violation as a function of the expected cost. This relationship shows that as the expected cost of a violation increases due to an increase in the probability of detection brought about by additional compliance monitoring, the optimal violation decreases but at a diminshing rate (this relationship may be inferred from both Figure 20 and the derivatives of Equations 5 and 7). Finally, the upper

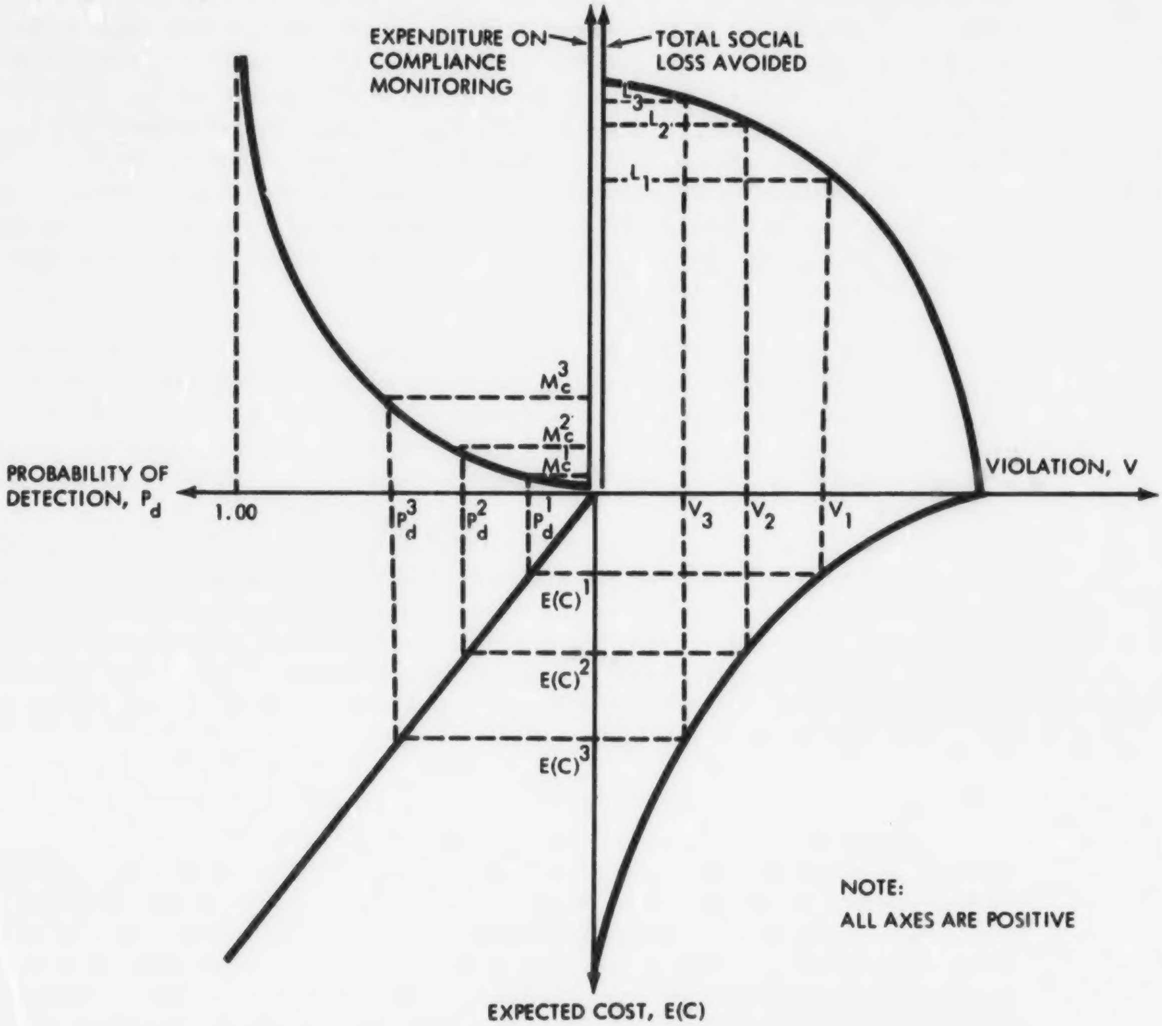
EXPENDITURE ON COMPLIANCE MONITORING
TOTAL SOCIAL LOSS AVOIDED
L_3
L_2
L_1
M_c^3
M_c^2
M_c^1
PROBABILITY OF DETECTION, P_d
1.00
P_d^3
P_d^2
P_d^1
V_3
V_2
V_1
VIOLATION, V
$E(C)^1$
$E(C)^2$
$E(C)^3$
NOTE:
ALL AXES ARE POSITIVE
EXPECTED COST, E(C)

Figure 25. Compliance monitoring and the total social loss avoided.

right quadrant shows the relationship between the violation and the social loss avoided. There is no connection between the upper left and the upper right quadrants. This is indicated by the two separate vertical axes—one measures expenditure on compliance monitoring; the other measures the social loss avoided.

To establish the relationship between the probability of detection and the total social loss avoided, assume that the expenditure on monitoring is increased from M_c^1 to M_c^2 in order to increase the probability of detection by one unit from P_d^1 to P_d^2. This increases the expected cost from $E(C)^1$ to $E(C)^2$ which decreases the optimal violation from V_1 to V_2. As a result the total social loss avoided increases from L_1 to L_2. If expenditure on monitoring is increased to M_c^3, probability of detection is increased by one more unit and the total social loss avoided increases from L_2 to L_3. While the total social loss avoided increases as the probability of detection increases, it does so at a diminshing rate (because $L_3 - L_2$ is less than $L_2 - L_1$). Thus, the relationships between total social loss avoided and the probability of detection (i. e., the total benefit from compliance monitoring) and the marginal social loss avoided and the probability of detection (i. e., the marginal benefit from compliance monitoring) will appear as in Figure 26 and 27, respectively.

Figure 28 combines both the marginal benefits curve from expenditure on compliance monitoring and the marginal cost of compliance monitoring (illustrated in Figure 16). The optimal probability of detection is that probability where marginal benefit is equal to the marginal cost, i. e., where the two curves intersect at P_d^*.

Once the optimal probability of detection to aim for is established the optimal expenditure on compliance monitoring may be inferred. (See the discussion contained in preceding subsection, "Monitoring for Compliance," and Figure 12.) This identifies the optimal compliance monitoring budget. The optimal monitoring strategy (i. e., combination of monitoring techniques) may also be inferred because a unique monitoring strategy is associated with each level of probability of detection.

The optimal detection probability is not, in general, that which would induce perfect compliance with the standard. This is because it pays society to undertake additional compliance monitoring that pushes a permittee closer towards total compliance with the standard only so long as the incremental gain to society exceeds the incremental cost of the additional monitoring required. Thus, it should not be surprising to see marginal violations of quality standards. To use a rather precise analogy, the maximum highway speed limit is a standard which is enforced by policing the highways. The highways could be policed so intensively that no one would exceed the speed standard. However, they are not because

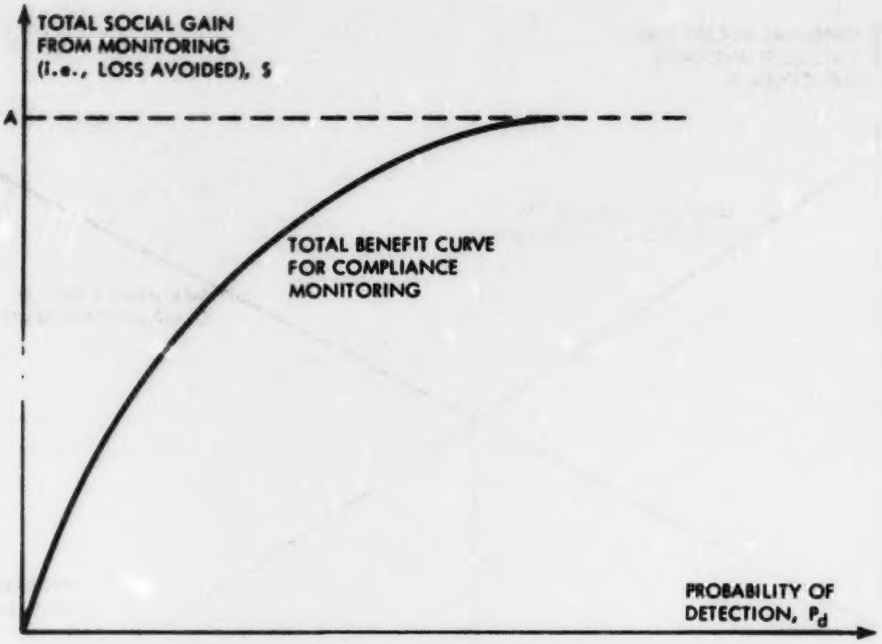

Figure 26. The total benefits from compliance monitoring.

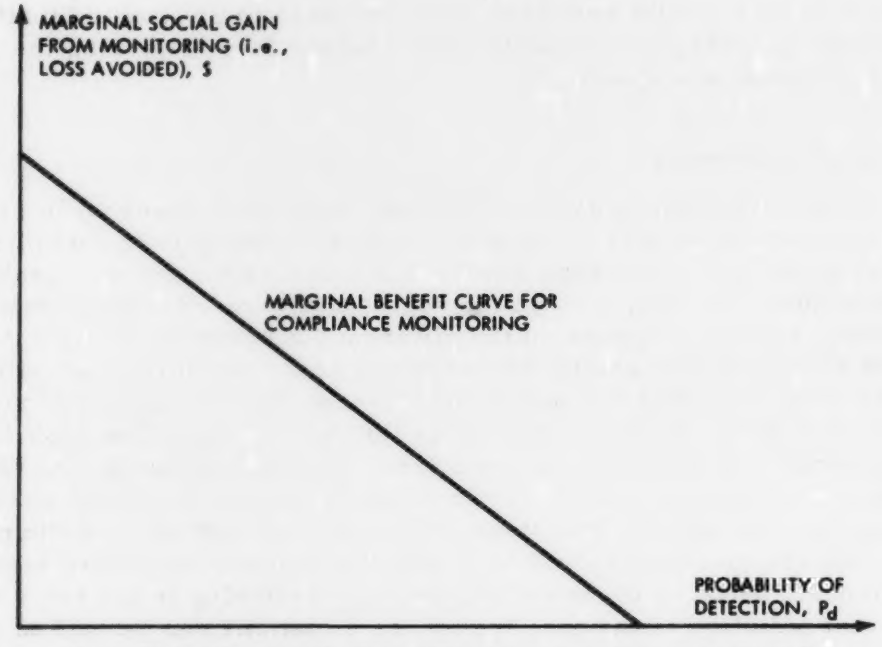

Figure 27. The marginal benefits from compliance monitoring.

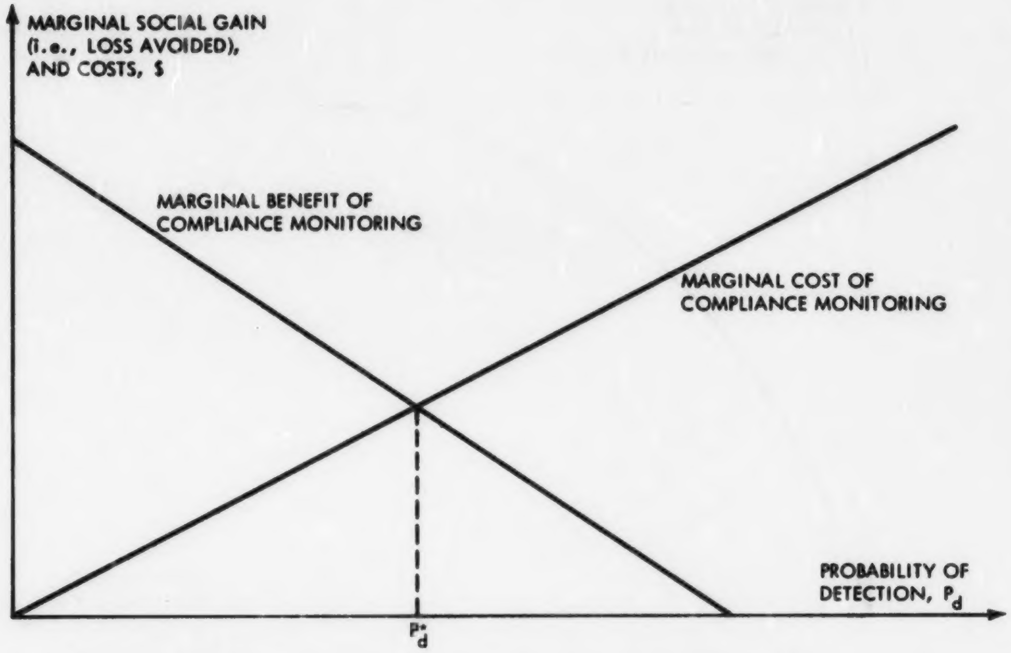

Figure 28. The optimal probability of detection.

the marginal social cost of such an increase in policing intensity would exceed the marginal social benefit obtained from deterring the relatively few persons who speed.

Monitoring Priorities

Figure 28 may be used to illustrate the issues involved in establishing monitoring priorities. Greater marginal benefits from compliance monitoring (for given marginal costs) will increase the optimal probability of detection. This depends on the social loss avoided through monitoring which, in turn, depends on the difference between the marginal damages and the marginal benefits associated with a certain level of pollution. The larger the difference between the marginal damages and marginal benefits from pollution, the higher the optimal detection probability and consequent expenditure on compliance monitoring should be. This inference is consistent with the notion that the larger the threat posed by a pollutant the stricter the standard imposed should be, and the more assiduously the situation should be monitored in order to assure standard compliance. Thus, if the marginal cost of monitoring is the same for different pollution situations, then those situations can be ranked according to the threat that they pose for society.

Conversely, the optimal probability of detection will increase with lower marginal costs of monitoring (for given marginal benefits). Thus, different pollution situations that pose an equal threat to society can be prioritized by ranking them according to the marginal cost of monitoring them. The lower the marginal cost, the higher the probability of detection which should be aimed for and the larger the fraction of the total expenditure on monitoring which should be allocated to those cases. Considerations such as these argue for a greater allocation of monitoring expenditures to point sources as opposed to nonpoint sources (such as sewer lines, agricultural runoff, etc.) since the former have lower marginal costs of monitoring than the latter.

Corruption

Although the objective analysis of dishonesty may be distasteful, this does not make dishonest behavior any less prevalent. Regrettably, government regulations are sometimes broken either willingly or on payment of a bribe (perhaps disguised as a wage premium). Even more regrettably, it is not unknown for government employees (cloaked as "inspectors" or "monitors") to collude in the violation of regulations.

To this point the analysis has assumed that when it is beneficial for a permittee to violate a groundwater quality standard he will do so with impunity. This assumption implies that the permittee's employees obey the permittee's directions even when they are illegal, but it is highly likely that some of the employees will balk at taking actions which they know to be illegal. One of the permittee's options if he is faced with a recalcitrant employee might be to fire him and replace him with a more tractable employee. It is to prevent such blatant victimization of honest employees that the Federal Water Pollution Control Act states, in Section 507(a), that "No person shall fire, or in any other way discriminate against . . . any employee (who) . . . caused to be filed . . . any proceeding under this Act. . ." If, after an investigation and hearing, a fired employee is vindicated, the permittee may be enjoined to reinstate the employee with retroactive pay and compensation for costs and expenses in filing the complaint. (PL 92-500, Section 507(b).) As an aside, such a weak protection clause would not seem to provide much incentive for employees to assist in enforcement of the law.

The permittee's second alternative is to move a recalcitrant employee to other activities and replace him with a more tractable employee. Presumably, if the employee were not demoted he would find it difficult, and would have little incentive, to prove "discrimination."

Up to now it has been implicitly assumed that the permittee's employees would willingly follow the permittee's directions even though that meant breaking the law, or that he was able to replace recalcitrant employees with tractable substitutes, without incurring any additional costs. In a competitive job market this might prove to be close to the truth, especially when adherence to the standard itself would, if anything, tend to make jobs scarcer by reducing the optimal scale of the permittee's activity. The possibility of quality standards adversely influencing employment opportunities is recognized in Section 507(e) of PL 92-500, which states that "The Administrator shall conduct continuing evaluations of potential loss or shifts of employment which may result from the issuance of any effluent limitation . . . including . . . investigating threatened plant closures or reductions in employment . . ." However, it is possible that none of the permittee's employees would be willing to violate the law without additional compensation. Thus, the permittee's third option is to pay employees a wage premium (i. e., a bribe) in order to induce them to implement the standard violation he has decided upon. It is plausible to assume that this bribe would be an increasing function of the size of the violation desired by the permittee. That is,

$$B_1 = h(V) \quad ; \frac{\partial B_1}{\partial V} > 0 \ , \qquad (8)$$

where B_1 is the cost of the bribe to the permittee. Addition of this cost to the permittee's other expected costs, as given by Equation 6, results in

$$E(C) = f(M, V) \cdot j(V) + h(V) \quad . \qquad (9)$$

Instead of the original expected cost curve shown in Figures 19 and 20, there would be a new curve everywhere above the original curve and diverging from it as V increases (i. e., with a greater slope at any V than the original curve), with the implied optimal violation less than V_1. Apart from this minor modification, none of the previous analysis is altered by making allowance for the permittee to bribe employees to violate groundwater quality standards. In fact, even this minor modification does not arise if the required bribe is not a function of the size of the violation but is a fixed amount ($\overline{B}_1$) independent of the size of the violation. If this is the case, then the cost curves in Figures 19 and 20 shift up by $\overline{B}_1$ without changing their slope and, therefore, without changing the optimum violation (V_1). The only effect in this situation is on the distribution of the permittee's gain. The permittee would now retain only B - $\overline{B}_1$ while $\overline{B}_1$ would be transferred to his employees.

While it is not common for government employees to collude in the violation of regulations they are supposed to enforce, it is not unknown. Thus, for completeness' sake the analysis should consider what would happen if the government employee responsible for enforcing compliance is corruptible.

It seems plausible that the bribe demanded by the government "monitor" B_2 would be an increasing function of the violation proposed by the permittee. Thus,

$$B_2 = k(V) \quad ; \quad \frac{\partial B_2}{\partial V} > 0 \quad . \tag{10}$$

In general, it must be assumed that employees would continue to require bribing to violate standards notwithstanding collusion by the government monitor. Thus, the permittee's new expected cost function is given by

$$E(C) = h(V) + k(V) \quad . \tag{11}$$

In this new expected cost function the first multiplicative part of the expected cost function, $f(M, V) \cdot j(V)$, in, for example, Equation 9 has dropped out. That is because the probability of detection is assumed to be zero given that the government monitor has been suborned. Instead of the original expected cost curve shown in Figures 19 and 20 there would be an entirely new linear curve with a slope equal to $[(\partial B_1/\partial V) + (\partial B_2/\partial V)]$. Naturally the slope of this new curve would be equal to the slope of the permittee's expected gain curve (which is unchanged) at a higher optimum value for V because only then will collusion by his employees and the government monitor have increased his maximum net expected gain.

If the bribes paid to employees and the government monitor are not a function of the size of the violation but fixed amounts $\overline{B}_1$ and $\overline{B}_2$ that are independent of the size of the violation, a worst case occurs; the new expected cost curve is a horizontal line at $(\overline{B}_1 + \overline{B}_2)$. Consequently, the permittee maximizes his net expected gain by violating the standard by SR. In short, he operates as though no standard existed. Referring back to Figure 9, the cost to society would equal $A + M$ where M is equal to the alleged "monitoring" expenditure, or an amount that exceeds the loss to society which occurs if no standard and monitoring are imposed. Apart from imposing on society the additional cost of M for monitoring, corruption of the monitors merely imposes a transfer of the permittee's gain. The permittee would now retain only $B - (\overline{B}_1 + \overline{B}_2)$, with $\overline{B}_1$ being transferred to his employees and $\overline{B}_2$ to the government monitor.

Implementation Problems of Monitoring

Some practical difficulties attend the implementation of the optimal compliance monitoring strategy. While the optimal probability of detection to aim for is that level at which the marginal benefits from compliance monitoring equal the marginal costs of compliance monitoring (see Figure 28), it is inconceivable that this level (and implicitly optimal level of expenditure on compliance monitoring) will remain unchanged over time. It would only remain unchanged over time if all the underlying elements of the marginal benefit and cost curves remain unchanged. For example, the marginal cost curve for compliance monitoring will change as technological innovations in the monitoring industry occur and as the relative prices of various alternative monitoring techniques change. Similarly, the marginal benefit curve will change as the marginal social gain from monitoring (i.e., the loss avoided) changes. And this will change as the polluter's marginal benefits function from emitting pollutants and the pollutee's marginal damage function from the impact of pollutants change (which changes the optimal level of pollution). These marginal benefits from pollution emission and marginal damages caused by pollution are themselves dependent on the cost of the factors of production and the prices of the products that the polluter and his victim are confronted with. These factor costs and product prices will inevitably change with the passage of time. This will change the optimal level of pollution, the optimal probability of detection, and the optimal level of compliance monitoring expenditure. It is apparent, then, that the determination of the optimal level of pollution and, from that, the optimal probability of detection is not a once and for all exercise. Quite the contrary, in principle these change continuously through time and, consequently, any optimal strategy would require continuous applications of time and resources to its discovery and implementation. Indeed, it is quite conceivable that the transaction costs involved in continually determining and implementing the optimal monitoring strategy would exceed the social gain from its implementation (in terms of the net social loss avoided). If that is the case, then it follows that it is not in society's interest to follow that strategy. Moreover, the hypothetical case employed in this analysis to illustrate the economic principles involved in the determination of an optimal monitoring strategy was chosen for its simplicity. The example involved one identifiable polluter emitting one pollutant which damages one other party. If the practical implementation of an optimal monitoring strategy on a continuing basis is likely to prove so difficult in such a simple situation, one can only conjecture how much more complicated and costly the implementation of such a strategy would prove to be in situations where multiple polluters, multiple pollutants, and multiple pollutees exist, or for nonpoint sources of pollution. However, this does not necessarily mean, purely on the grounds of economic efficiency, that nothing should be done to preserve the quality of the Nation's groundwaters.

THE PRAGMATIC ALTERNATIVE—SECOND-BEST SOLUTIONS

Standard Setting

Since implementation of the optimal monitoring strategy on a continuous basis through time may impose more costs than benefits on society (in terms of social loss avoided), this section examines second-best solutions as a pragmatic alternative to this dilemma. (The term "second-best" is used in the theory of welfare economics in reference to non-pareto-optimal situations (i. e., when one transactor can be made better off without any other transactor being made worse off). The term as used here is only loosely related to the rigorous way in which it is used in formal theories of second-best choices.) Essentially, second-best solutions capitalize on the fact that rational action can be predicated on limited information concerning the polluter's total benefit function from emitting pollutants and the pollutee's total damage function from the impact of pollutants.

The limited information that is required in order to implement some form of second-best solutions is illustrated in Figure 29. The two dashed

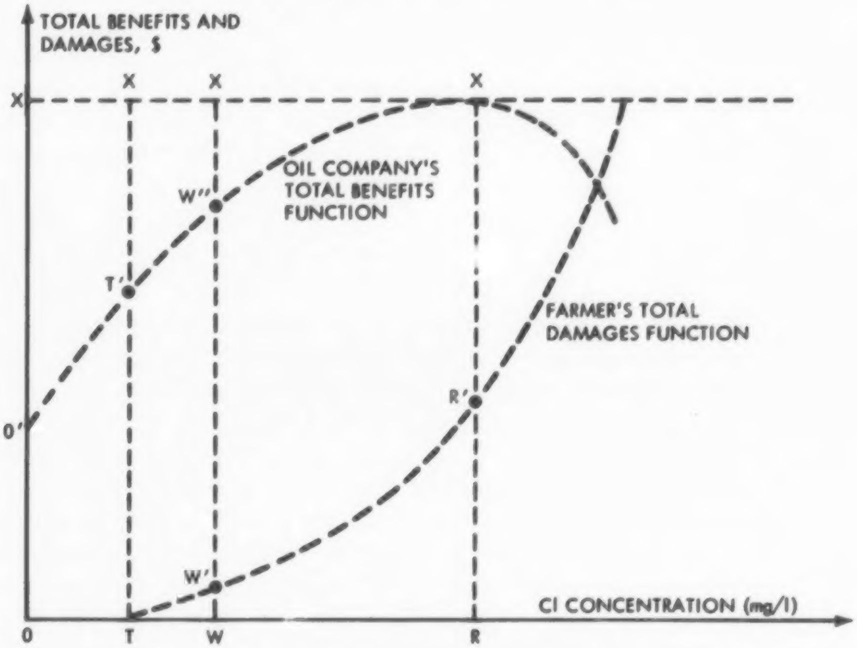

Figure 29. Second-best alternatives.

curves in this figure are the farmer's total damages function and the oil company's total benefits function first presented in Figures 5 and 7, respectively.

These two curves are shown dashed in Figure 29 as a reminder that their precise, or complete, configuration is assumed not to be known. Information on these damages and benefits is restricted as follows:

1. The damages sustained by the farmer when the oil company's activities are unconstrained. These are the damages associated with the level of chloride concentration at the farmer's well equal to 0R ; namely, RR′. The total benefits to the oil company are equal to RX (a maximum).
2. The chloride concentration at the farmer's well at which the damages sustained by the farmer would be zero. This is the threshold-level of chloride concentration in Figure 29. (The threshold may, of course, be zero chlorides. In general, however, it will be some positive level.)
3. The cost to the oil company of reducing the chloride concentration at the farmer's well to the threshold level 0T. This is the reduction in the present value of the oil company that is implied when it adopts the least-cost way of reducing the chloride concentration at the farmer's well to 0T (an amount XT′ in Figure 29). In principle, XT′ may be infinite if no economically feasible techniques exist for lowering the chloride concentration level to 0T. In general, however, it will not be.
4. The damages sustained by the farmer, and the cost to the oil company, associated with the reduction of the chloride concentration level at the farmer's well to that attainable when the "best practicable control technology [BPT] currently available," is adopted (USEPA, 1974). These damages and costs are WW′ and XW″, respectively, while the chloride concentration level associated with BPT is 0W. (The chloride concentration level associated with BPT may be less than the threshold level, i.e., 0W may be less than 0T. When the threshold is less than BPT, XT′ —i.e., the reduction in the present value of the oil company implied when it adopts

> the least-cost way of reducing the chloride concentration at the farmer's well to the threshold—would be expected to be very large. In other words, the total benefits function falls off precipitously to the left of W'' because of the extremely high cost of lowering pollution levels below BPT. In principle, the $0'W''$ part of the total benefits curve could become a negative value.)

If complete information were available on the total damage and benefits curves, the optimal level of pollution to adopt would be that level at which the divergence between the two curves was a maximum. This would correspond to the level 0S (not shown, but between 0W and 0R). However, assuming that this complete information is costly to acquire compared to the cost of acquiring the smaller amount of information discussed in items 1 through 4, above, the question is not whether to implement 0S (the optimal, or "first-best," policy when information is complete) but which of the second-best policies 0, 0T, 0W, or 0R to implement given the limited information that is available or may be acquired relatively inexpensively.

The principle governing the decision is the same; namely, select that second-best alternative with the largest net benefit to society. Diagrammatically, this amounts to selecting the second-best policy from the subset, 0, 0T, 0W, and 0R at which the difference between the oil company's benefits and the damages to the farmer is the largest. For purposes of illustration, in Figure 29 this is seen to be the BPT policy, 0W, since $W'W''$ exceeds $00'$, TT', and XR'. Of course, the 0, 0T, and 0W policies also involve monitoring and other enforcement costs which the 0R policy does not. Thus, 0W is, in fact, the desired second-best policy only if $W'W''$ exceeds XR' by at least as much as the monitoring and enforcement costs required to implement that policy.

Pragmatically, in setting standards the EPA is confronted with the decision whether to allow the oil company's activities to continue at the unconstrained level (0R) or whether to set some new standard such as BPT, threshold, or zero pollution. To decide which is the appropriate second-best standard, the EPA would have to estimate the reduction in damages to the farmer for each policy and subtract from this the additional cost to the oil company plus the monitoring and other enforcement costs for each policy. The policy for which this difference was largest is the appropriate second-best policy (as long as the difference is positive). By way of illustration, in Figure 29 the 0W policy reduces the damages to the farmer by $R'W'$ while increasing the oil company's costs by XW''. The net benefit to society from changing to this standard is, therefore, (R′W′) - (XW″ + M_w) where M_w is the monitoring and other enforcement costs associated with the BPT standard. The net benefit to society from changing from 0R to 0T would be (R′T) - (XT′ + M_t) where M_t is the monitoring and other enforcement costs associated with the threshold standard; and the net benefit to society from changing from 0R to 0 would be (R′0) - (X0′ + M_o) where M_o is the monitoring and other enforcement costs associated with the zero pollution standard. In principle, M_w, M_t, and M_o may differ.

Monitoring

The previous subsection argues that, in a second-best situation, the appropriate policy is to select that standard for which the difference between the reduced damages to the farmer and the additional cost to the oil company plus the monitoring and other enforcement costs was the largest. However, this says nothing about what the optimal expenditure on monitoring should be. The reason for this omission is that, in a second-best situation, there is not sufficient information to infer the optimal expenditure on compliance monitoring. This can be explained by referring back to Figure 28 and, in particular, to the marginal benefit curve for compliance monitoring. That curve in turn was derived from Figure 26 which shows the total social gain from monitoring (in terms of loss avoided) as a function of the probability of detection. But the gain was defined in terms of the area between the marginal benefits and damages functions associated with various levels of pollution (see Figure 23). However, these latter two curves depend on complete information concerning the total benefit and damage curves associated with pollution and, by definition, in second-best situations such complete information is not available. By this chain of reasoning, in second-best situations the marginal benefits curve from compliance monitoring is not discernible, and thus the optimal probability of detection to aim for (which also is implicitly optimal for compliance monitoring) cannot be identified.

There seems to be no answer to this particular difficulty except to make certain that if a second-best standard is set, the monitoring and other transactions costs imposed to enforce compliance with the standard are no greater than the difference between the reduction in damages to the farmer and the increase in costs to the oil company. As long as the expenditure is kept below that difference society gains; if it equals that difference society is no better or worse off and the second-best policy would only have distributional effects; if it exceeds that difference society loses.

The foregoing discussion of implementation problems and second-best solutions serves to show how difficult it proves to be for the government to set and enforce economically efficient groundwater quality standards by direct regulation. Because of these difficulties, Section V explores an alternative method of obtaining an economically efficient level of groundwater quality which relies on a respecification of the private property right to that resource.

SECTION V

WASTE RELOCATION RIGHTS: AN ALTERNATIVE SYSTEM OF GROUNDWATER MONITORING AND POLLUTION CONTROL

In general, it is analytically incorrect to argue that pollution should be eliminated. As with most other things, there is an optimal amount of pollution. The burden placed upon regulatory authorities is to design institutional arrangements that will achieve that optimum. The analysis in Section IV of the set of institutional arrangements required to achieve this end through direct government regulation by issuance of permits shows that considerable, perhaps insuperable, difficulties lie in the way of this option.

This section discusses in some detail a second scheme for regulating groundwater quality which revolves around what is described as a "Waste Relocation Right." The associated monitoring requirements for this regulatory scheme are also addressed.

It is recognized that the concept of waste relocation rights is controversial and would require considerable modification of existing institutional and legal mandates in order to be implemented. As a consequence it must be stressed that a regulatory scheme based on waste relocation rights does not necessarily reflect EPA policy.

ADMINISTRATIVE VERSUS NONADMINISTRATIVE POLLUTION MONITORING AND CONTROL

Most attempts to monitor and control groundwater pollution in the United States have involved administrative regulations. Discharge permits, for example, set allowable upper limits on the amount of pollutants that may be disposed of into the ground at a point source. This limit is set by statute or regulation by the cognizant administrative agency. Most of the proposals for new methods to monitor or control pollution, including effluent disposal charges, also involve mainly administrative techniques. Although a pollution regulatory system based on effluent "fees" is thought by some to be a market-oriented type of pollution control, it too is more an administrative than a market system. Although the polluter is allowed to vary his disposal techniques according to his comparison of the cost of the fees paid for injection and the cost of alternative means for waste disposal, the fee is determined administratively; it is not a price that fluctuates according to the market processes of demand and supply. Moreover, most monitoring under the administrative regulatory system is performed by public agencies. Under a nonadministrative system, monitoring would be undertaken more often by private parties through the ordinary market processes of transactions among strangers.

The U.S. system of basically administrative control of monitoring and pollution is too new to yield much knowledge of its overall impact on society. Among the benefits of administrative regulation have been monitoring of severe pollution situations, preventing deterioration of some important aquifers by pollution, and drastically limiting disposal of such dangerous pollutants as chromates. In spite of these benefits, however, it is difficult to judge whether such regulation has on net improved society's welfare. Administrative regulations are imperfect instruments for controlling and monitoring pollution. The responsible agencies may not possess all the information required to ascertain existing or optimal pollution levels. They may devote too many or too few resources to monitoring. Once rules and regulations on monitoring and pollution control are implemented, they are often costly and cumbersome to change even if circumstances alter rapidly. The requisite monitoring and compliance data to assure that no more than the economically optimal amount of pollution occurs might become available eventually. But agencies might lack incentives to employ these data and to pursue social optimality single-mindedly to the exclusion of internal bureaucratic goals. Moreover, an agency devoting itself too zealously to the reduction of pollution might curtail certain pollution-causing economic activities that would be of greater benefit to society than the value of removing the pollution associated with them. Unfortunately, there is little evidence to suggest that administrative regulation of monitoring and pollution has resolved these problems in a fashion that would, overall, benefit society. Thus, given today's meager knowledge, it is literally the case that past experience with administrative regulation of groundwater pollution and monitoring raises more questions than it answers.

A recognition that the existing system of pollution and monitoring control is imperfect evidently has not troubled many officials or citizens, probably because the existing system of regulation, with all its warts, is considered to be superior to "no regulation," the only alternative that has been conceptualized in the public's mind. But the criticism against the existing administrative system could be taken seriously if there were a feasible nonadministrative system of regulation that could prevent uneconomic aquifer degradation while containing fewer of the pitfalls of administrative regulation.

One nonadministrative system of groundwater pollution monitoring and control that could be considered as a legitimate alternative to improve the overall efficiency with which the Nation's aquifers are used has as its basic element a waste relocation right.* The term "waste relocation right" is used here in recognition that wastes, or residuals, are the inevitable result of man's activities and that, equally inevitably, they must be relocated somewhere. The problem is, of course, to get them optimally relocated. The waste relocation right is a grant to each land owner which entitles him to protection from pollution above a specified amount in the groundwater underlying his land. This right would be exchanged among persons through ordinary market processes and would be enforced by the existing U. S. legal system. It would not require the creation of new, untried, and potentially expensive governmental agencies. This would be an essentially private system of pollution monitoring and control, with limited government supervision, based on the self-regulating forces of existing and tested market processes and legal institutions.

Waste relocation rights would be analogous to mineral leases and tied to the ownership of land. Pollution of groundwater underlying another party's land would be prohibited without first purchasing that party's waste relocation right. Such rights would be valuable, freely transferable, and command prices in the marketplace. They would be exchanged privately in much the same fashion as titles to land are now bought and sold. Monitoring for pollution in excess of the allowable levels would mainly be through private contracting. Enforcement of property owners' rights would be through injunctions or monetary damages awarded by courts. Thus, the waste relocation rights scheme would rely upon and harmonize with the basic processes by which rights to other resources in this country are exchanged and protected.

The remainder of this section describes the waste relocation rights system and its ability to cope with the peculiar and sometimes severe problems presented by groundwater pollution. Detailed are the nature of the rights, the advantages of court enforcement by a rule of strict liability, problems in setting the initial limits on the amount of waste that may be relocated, the processes and costs of exchanging rights, the protection given by the system to nonowners of land and environmental groups, and some potential problems in the operation of this property system including situations where it might not be applicable.

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*For discussion of a surface water waste relocation right scheme, see Dales (1968), Chapter 6. Dales calls his contract a "pollution right." However, the term "pollution right" has been countersloganized in the phrase "there can be no right to pollute" which, though wrong, has emotional appeal to those who traffic in slogans rather than analysis.

WASTE RELOCATION RIGHTS*

Assume that there are n pollutants in the range of $1, \ldots, n$ and that there are m holders of waste relocation rights in the range of $1, \ldots, m$. P_{ij} would then designate the maximum allowable level of the i^{th} pollutant underlying the land of the j^{th} individual. For example, if the 4th pollutant were chlorides, P_{4j} would represent the maximum concentration of chloride pollution (e.g., 300 milligrams per liter of water) that rightsholder j would legally be required to sustain under his land. P_{6j} could be the maximum allowable biochemical oxygen demand for organic material for water under j's land; P_{7j} could refer to the maximum parts per million for dissolved solids in the water under j's land; and so forth.

Under a waste relocation rights scheme, the owner of each legally defined parcel of land or his assignee in any of the United States would be granted by either Federal or State statute a package of rights and duties regarding the use and enjoyment of the waters underlying his land. This package would contain paragraphs to the effect that:

1. He is granted the exclusive right to engage in economic or other activities on his land which originally degrade, change, or pollute the water underlying that land to any extent, provided that the level of pollution which originates from his land does not exceed P_{ij} in the groundwater at any point beyond the boundaries of his land.

2. He is granted the right to be free of pollutants in the water underlying the boundaries of his land, which may originate from activities on the land of any other owner or his assignee in the United States, and which degrade, change, or pollute the quality of the groundwater underlying the boundaries of his land beyond the levels P_{ij} referred to in item 1.

3. For violation of the duty defined in item 2, an owner of land or of waste relocation rights shall, upon proof by any other owner of a violation, be required to adopt the least-cost method of restoring the quality of groundwater to the level P_{ij} specified in item 1 within a

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*The basic analysis contained in pages 69 to 81 of this report is analogous to and drawn from the property system for electromagnetic radiation found in De Vany et al. (1969). The important contributions of Professor Charles J. Meyers to the conception and the legal drafting of these property definitions are gratefully acknowledged.

period of M months, where M is determined according to accepted practice for models of groundwater flows for particular aquifers, given the maximum levels of pollution P_{ij}. In addition to the foregoing relief by injunction, the complainant may recover such pecuniary damages that he may be able to prove in a court of law as having been caused by said violation.

4. All owners of land or waste relocation rights must register their rights to groundwater use, including any subsequent exchange or recombination of those rights, in a central registry maintained by the cognizant governmental agency for public access by any owner of land.

5. A party suspecting a violation of his waste relocation rights may install monitoring devices on his own property, and he may install at his expense such devices on the property of other owners with their express consent.

6. There shall be no restraint upon the transfer or exchange between two or more owners of land of all or any part of the waste relocation rights which are specified in items 1 and 2, either as to:

   a. Changes in the boundaries of land beyond which pollution in the underlying groundwater may not exceed the limit P_{ij}, or

   b. Changes in the intensity of the pollution of groundwater to a quality different from the P_{ij} defined in item 2 within the boundaries of the owners of land or waste relocation rights who are parties to the exchange

   provided, that this exchange does not result in levels of pollution in excess of the original P_{ij} specified in item 1 for the groundwater underlying the land of any owner of waste relocation rights who has not been compensated for this higher pollution or whose permission has not been obtained.

COURT ENFORCEMENT AND STRICT LIABILITY

The waste relocation rights regulatory system would be created by statute but enforced by adversary proceedings in courts of law. This enforcement procedure appears to have several advantages. First, there is already a long-standing body of case law on groundwater pollution, so the courts are familiar with the often technologically complex questions raised by groundwater pollution and monitoring problems. (See, for example, Corker (1971), Knodell (1967), and Meyers and Tarlock (1971).) The courts could probably enforce groundwater rights more successfully than would relatively untried administrative agencies. Second, the tendency of the courts to settle fresh cases on the basis of precedent would give owners of waste relocation rights some confidence over the nature, extent, and value of their resources. Third, the adversary nature of court proceedings would focus on the competing harms involved in pollution cases—i.e., whether the polluter is to impose the cost of lower water quality on the pollutee or the pollutee is allowed to shut down some or all of the polluter's economic activities. Coase (1960) has argued that courts often take these economic factors into account in reaching decisions. If the process by which courts weigh competing harms usually leads to selecting in favor of the least economic cost, then efficient resource use would be promoted.

In general, there are two broad alternative rules of liability for pollution that the courts might impose: fault (or tort) versus strict liability. Under tort law, liability usually depends not just on the actual violation but upon such factors as the reasonableness of the violation or whether the defendent intended to harm the plaintiff. (See Section II.) Alternatively, under the rule of strict liability, a defendent's guilt is determined by only the fact of his violation of a duty owed to someone else, and not by the degree of the violation, his state of mind, or other extenuating circumstances.

According to the waste relocation right, liability for violations would be strict (De Vany et al., 1969). Referring to item 3 of the right, if rightsholder A monitors for pollutant 4 under his land and finds more than the allowed P_{4A} which is traceable to rightsholder B, then A's remedy is to sue B for the violation of duty which B owed to A. A may sue B either for an injunction forcing B to reduce the pollution to an amount within the P_{4A} constraint before M months have elapsed; for damages which A can prove he sustained as a result of pollution from B in excess of P_{4A}; or for both an injunction and monetary damages. All that matters in court is whether B's actions led to more than P_{4A} pollution being found in the water underlying either A's land or the boundaries of his waste relocation right. It does not matter whether B's violation in exceeding P_{4A} was the result of intent, carelessness, ignorance, malevolence, or stupidity. It also does not matter whether B may have exceeded the P_{4A} limit by a small or "reasonable" amount for a short period of time. If B exceeds P_{4A} by any amount no matter what the reason may be, he is guilty under a standard liability if A chooses to enforce his right.

A standard of strict liability is rarely found in the existing law of groundwater pollution. (See Section II, particularly quotations from Corker (1971).) The guilt of the polluter is usually determined by one of several tort law concepts that seek to determine the nature of fault for pollution. The determination of fault raises additional questions beyond the simple and sole question raised by strict liability—whether B's pollution under A's land exceeded P_{4A}. In some situations, tort law determines guilt according to whether the polluter intended to harm the pollutee, or whether the polluter had been careless or negligent in failing to exercise a prudent degree of care in his pollution-causing activities. In still other cases guilt depends upon whether the pollution caused a nuisance to the pollutee.

An economic objection to enforcement by a rule of tort liability is that transactions costs would be raised and the incentives for efficient use of resources would be weakened because the process of making and enforcing transactions consumes additional resources. It includes the costs for both buyers and sellers of searching out, negotiating, and enforcing mutually beneficial exchange opportunities. This involves hiring surveyors, lawyers, and other consultants. Sometimes it is necessary to go to court when voluntary compliance is not obtained or when the parties are in disagreement over whose right is dominant. When these costs are relatively high, the incentives for rightsholders to enter into exchanges will be limited: if the cost of making an exchange exceeds its value to either party it will not be completed. Relatively high transactions costs will dampen and limit the efficiency of the economic process by which rights to resources move from lower valued to higher valued uses and users. Thus, in designing new property rights, care should be taken to minimize transactions costs in order to encourage beneficial exchange.

One factor that will almost always impede exchange is a vague definition of rights or liabilities. The more uncertain rights and duties are, the greater the transaction and litigation costs will be. In the cases of tort law, a legal determination of the meaning of such ambiguous standards as "reasonableness," "negligence," "good faith," or "intent," would be so lengthy and expensive that these concepts could scarcely be termed standards at all. If they could be given legal meaning, it would only be by a lengthy ad hoc procedure where each situation is adjudicated according to its particular facts, individuals, personalities, intentions, etc.

(De Vany et al., 1969). Since there really is no "standard" of tort liability, each case would require a separate adjudication and its result would be in doubt until the verdict was in (Corker, 1971). This would increase an owner's uncertainty about the value of his rights, tempting him to try litigation before he bargains with his "adversary." This action avoids his purchasing a right that a court might later decide he already owned, or adjusting his economic activities to reduce pollution when not required by law. Thus, nebulously defined rights reduce the likelihood of bargaining, increase transactions and litigation costs, and reduce the probability that society's scarce resources will be used optimally.

Whether legal critics have found an acceptable substitute to tort liability, as Corker alleges they have not, is open to dispute. In the case of waste relocation rights, a standard of strict liability would lower transactions costs by raising "one, and only one, triable issue of fact: What was the [level of pollution] at the time in question?" (De Vany et al., 1969). Did it exceed the maximum P_{ij} level? This would not always be an easy question to answer. Substantial resources would often have to be devoted to the problem of monitoring and proving groundwater pollution. But it is probably an easier question to answer than the questions raised by tort liability rules.

THE ZERO WASTE RELOCATION "RIGHT"

The preceding comparison of fault versus strict liability rules also suggests that a regulatory system of waste relocation rights which sets the initial P_{ij} equal to zero would not promote the efficient use of resources (De Vany et al., 1969). Although some might find it appealing to specify waste relocation rights that allow zero increments to groundwater pollution, these "rights" would have little value. As a practical matter, pollution increments cannot literally be reduced to zero without curtailing most human and economic activities. The practical result of setting an initial limit of 0 mg/l of, say, chlorides would be to give polluters the right to inject chlorides up to the point where they did not cause excessive harm to the groundwater underlying the land of their neighbors. But, as has just been argued, a right defined in terms of excessive harm entails an enforcement mechanism having relatively high transactions costs. Each case of violation under the zero pollution right, as with the fault rule of liability, would have to be adjudicated separately in order to determine what constituted excessive harm in various circumstances. This increased degree of uncertainty would lead parties to litigate rather than bargain and would curtail exchanges, all of which would diminish the efficiency of resource use. Thus, on grounds of economic efficiency, the waste relocation right should be defined at some positive level rather than at zero.

SETTING THE INITIAL WASTE LEVELS

Each landowner has thus far been hypothetically granted a package of rights and duties: first, a right of protection from a certain level of pollution caused by others in the groundwater underlying his land; and second, an obligation to refrain from causing this same level of pollution to be exceeded in groundwater underlying all other parcels of land. Thus, all landowners have a structure of symmetrical rights and duties concerning groundwater pollution. The permissible amount of pollution is determined by the original limits of the P_{ij} and by the subsequent process of exchanging these rights in the marketplace.

The initial P_{ij} limits would be set after a series of once-and-for-all hydrologic, biologic, chemical, and economic studies established tolerable and economically usable amounts of P_{ij}. These would result in packages of rights that would have monetary value. Two of the P_{ij} features should be stressed. First, the initial levels should usually be slightly in excess of ambient levels of pollution. P_{ij} greatly in excess of ambient levels would permit rightsholders to substantially increase pollution without obtaining consent from the affected parties. P_{ij} significantly below ambient pollution levels should also be avoided. This would force some landowners to "clean up" the waters underlying their property before the land could be used for any purpose, possibly imposing significant losses on them.

Second, the initial P_{ij} must be usable but need not be perfect. That is, they need not be economically optimal or ideally suited to the use that would result on a given parcel and all surrounding parcels of land with existing technological and market conditions. The cost of amassing the information required to determine optimality at the outset would be enormous. Such information is not presently available and would probably cost more than the several rounds of exchanges required to optimize the original rights packages. Moreover, the variables determining the optimality of rights packages—such as population concentrations, technologies, costs, and market demands—will undergo constant change. This requires that rights be restructured accordingly. Therefore, under the waste relocation rights regulatory system, the economically optimal amount of pollution and monitoring would be approached iteratively through market exchanges once usable packages of rights were created and assigned. The market exchange approach avoids the most serious difficulties associated with the administrative maintenance of the optimal level of groundwater quality via permits, the problem of the changing nature of that optimum through time (De Vany et al., 1969).

In most cases, the process of exchange would constitute the least expensive process for allocating waste relocation rights from lower to higher valued uses. To illustrate this, if brine pollution from the oil company example of this study were seriously affecting the crop yields of adjacent farmers, the farmers would have incentives to purchase the oil company's waste relocation right if the right were more valuable in agriculture than in industrial production. However, if it is known in advance that a particular level of pollution would be devastating to highly valuable activities located nearby—such as a municipal water supply—then exchange may not be the most efficient process for determining the optimal amount of pollution. In these cases it would be uneconomic to set the initial P_{ij} at a level that would devastate the higher valued use, and setting it at a lower, near zero level could avoid the cost of restructuring rights later on.

EXCHANGING WASTE RELOCATION RIGHTS

Two conditions must be met in order for optimality to be approached through market processes. First, the cost of making exchanges and recombining packages of waste relocation rights must be low relative to their value. Second, mutually beneficial exchanges between two or more transactors must not impose uncompensated costs in excess of P_{ij} pollutants on other rightsholders unless their consent is first obtained. Just as it is socially and economically undesirable for two transactors to impose harm on third parties without their consent, it is equally undesirable for the law to require that the consent of third parties be obtained before each exchange is concluded. The transactions costs required to achieve optimal resource use would be almost the same in each instance; in the first instance third parties must bargain with transactors to prevent the harm, and in the second instance transactors must "buy off" all third parties (De Vany et al., 1969). The definition of waste relocation rights avoids both extremes by allowing third parties to be subjected to pollution levels up to the P_{ij} threshold. As long as the P_{ij} limit is not exceeded, exchanges between two parties are not severely constrained and the extraordinarily high transactions costs and enforcement costs which usually accompany exchanges involving a large number of transactors can be avoided. When the effect of the exchange is to exceed P_{ij}, however, third parties must be brought in and compensated.

Waste relocation rights are, by the terms of the property definition, de jure covenants expressly tied to the ownership of land. Therefore, exchanges of waste relocation rights would be similar to exchanges of land with the exception that the transactors would be exchanging rights to alter (either improve or pollute) the quality of waters beneath the land without necessarily purchasing the land itself.

A landowner's sale of waste relocation rights to a party who seeks to alter the quality of groundwater is exactly analogous to a mineral right. For example, an oil company may buy or lease subterranean rights to drill or explore without buying the parcel of land itself. All the driller purchases is the owner's promise with respect to one use of the land. Exchanges of this sort occur commonly in spite of the large number of landowners with which an oil company may have to deal, especially in cases of slant drilling.

Land transactions may serve as a model for exchanges of waste relocation rights. Two primary types of exchanges will occur: restructuring all or portions of waste relocation rights without exchange of the land itself; and combining or subdividing rights as the result of the sale of land.

RESTRUCTURING WASTE RELOCATION RIGHTS*

Consider the simple situation of four landowners depicted in Figure 30 where the initial level of groundwater chloride content for each is set at 300 mg/l. Assume that landowners A, B, and C are farmers but that D begins to drill for oil and seeks to dispose of his brines via an unlined disposal pit. Knowing that the flow gradient in an underlying aquifer is from east to west and that all pollutants are traceable at low costs, D purchases B's rights (but not B's land) to create up to 300 mg/l of chloride pollution at any point beyond B's land. When B's rights are combined with D's initial right to achieve up to 300 mg/l of chlorides at any point beyond the boundaries of D's land, one might conclude that D has now obtained the right to create up to 600 mg/l of chlorides in the groundwater in the vicinity of the B/D boundary, but this is not necessarily

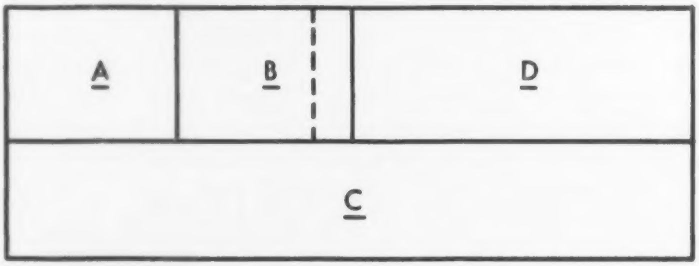

Figure 30. Land parcel diagram, chloride pollution example (P_{cl} = 300 mg/l).

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*The analysis of exchanges of waste relocations rights in this and the following subsection is based on the model of exchanges of radiation rights developed in De Vany et al. (1969).

so. Purchasing *B*'s right to create 300 mg/l of chlorides beyond *B*'s land automatically assigns to *D* the initial duty of *B* not to achieve more than 300 mg/l of chlorides in the waters underlying anyone else's land. Unless he deals with *A*, *D* has not obtained the right to impose more than 300 mg/l of chlorides west of the *A/B* boundary. *A*'s protection is maintained in spite of the exchange between *D* and *B*. Thus, in order for *D* to maintain his duty toward *A*, he may have to limit his brine concentration to substantially less than 600 mg/l of chlorides in the vicinity of the *B/D* boundary.

Similarly, the exchange between *B* and *D* does not relieve *D* from maintaining the initial protection of the water underlying *C*'s land from either *D*'s or *B*'s land. *D*'s brine disposal activities after the purchase of *B*'s rights must take cognizance of his duty toward *C* as well as *B*'s toward *C*, *B*'s toward *A*, and his own toward *A*. If any of these duties are violated even slightly, *D* could face a lawsuit. Again, an analogy to land law is apt. If *D* purchases from *B* the right to build a fence a few feet to the west of the *B/D* boundary for its full length, this sale does not change in any way the position of the *A/B*, *B/C*, or *C/D* boundaries.

Several conclusions follow from even this simple example of exchanging rights apart from the sale of land. First, in order to make room for his brine plume by purchasing *B*'s waste relocation rights, *D* will want to learn the direction of flow in addition to other characteristics of the aquifer and perhaps to model them. Second, *D* will monitor groundwater *before* and *after* the exchange occurs in order to make certain that he is not exceeding his own or *B*'s duties toward other owners of land. Third, the transaction between *B* and *D* does not require the consent of *A* or *C* unless their initial rights of protection against more than 300 mg/l of chlorides from either *B* or *D* are violated by the transaction. Transactors are allowed some latitude before having to deal with third parties such as *A* and *C*, but the extent of that latitude is determined by the initial P_{ij}. At least to this extent some transactions including many participants, with their high transactions costs, are avoided.

The preceding analysis also applies to two other subcategories of exchanges which amount to combining *portions* of waste relocation rights. In the first subcategory, *B* might agree to sell *D* the rights applying to the easternmost one-fourth of *B*'s land. This would permit *D* to achieve a maximum of 300 mg/l of chlorides at a new waste relocation rights boundary (represented by the dashed line of Figure 30) lying one-quarter of the distance westward from the *B/D* land boundary. As with exchanges involving sales of entire waste relocation rights, sales of portions of waste relocation rights would not allow *B* or *D* to violate their original duties toward *A* and *C*. Indeed, the contract between *B* and *D* would provide for *D*'s right to monitor on *B*'s land up to the dashed-line boundary so that *D* could make sure that he adhered to his obligation toward *B* not to exceed allowable levels of pollution. *B* would continue to monitor on his side of the boundary, and both *A* and *C* would continue monitoring along the edges of their lands to make sure their rights also were not violated by the exchange. *D*'s entire monitoring and modeling effort would indicate by how much he could increase pollution in the waters to the west and south of the dashed-line boundary. This would influence the price that *D* would be willing to pay *B* for this portion of *B*'s waste relocation rights.

The second subcategory of exchanges between *B* and *D* would be retain the initial solid-line *B/D* boundary but to increase the allowable amount of chloride pollution which *D* could release into the waters underlying *B*'s land to, say, 400 mg/l. However, this would not relieve *B* and *D* of their respective duties to achieve no more than 300 mg/l of chlorides in the waters under *A*'s or *C*'s land unless the permission of *A* or *C* were obtained. Again, some modeling and monitoring would be undertaken by both *B* and *D* before entering into this contract in order to protect themselves from liability toward *A* or *C*.

SALES OF LAND WITH WASTE RELOCATION RIGHTS

The waste relocation rights regulatory system allows rights to be exchanged separately from the sale of land. But assume now that the land is sold in its entirety with the original waste relocation rights intact. Assume also that, owing to the long-lived and slow-moving nature of groundwater pollution, a violation is not discovered until substantial time has passed after the pollution-causing activity occurred. If *A* sells his entire land to *Z* and *C* finds a violation of more than 300 mg/l of chlorides some time after this transaction, two questions arise. First, if liability is assigned, whether it should go to *A* or to *Z*, and whether *C* would sue *A* or *Z* or both. Second, whether liability should be assigned at all and whether *C* may sue anyone.

The critical issue for the first question is that the liability should be assigned fully to just one of the two parties (De Vany et al., 1969). Division of liability between the two is bound to be arbitrary in some degree and would promote controversy. This raises transactions and litigation costs. A more efficient solution would be to assign full liability to just one party according to either of two legal rules. The first rule, "last in time is first in right," would place the full liability on *A* which he could either retain or shift to *Z* at a cost to himself. The second rule, "first in time is first in right," would place the full liability on *Z* which he would take into account as he monitored for existing pollution levels and decided on his offer price to *A*. As before, *Z* could contract the burden of liability back to *A* (at a price) or keep it.

Each of these legal rules has similar implications for groundwater monitoring. Assume that A originally sold his land with waste relocation rights to E who eventually sold out to Z. Assume also that the P_{ij} had not changed between sales. Under the "last in time is first in right" rule, A would retain liability until A either died or was dissolved (depending upon whether A is a person or a firm). Liability would then pass to E even though Z currently owned title to the land and waste relocation rights. Since C has incurred a violation of *his* waste relocation rights he would have recourse against either A or E, who would regularly monitor the groundwater under what was once A's land to make sure that C's protection was maintained (or to determine for himself the extent of the liability to C). Under the "first in time is first in right" rule, Z would be liable for the violation of C's waste relocation rights. In this case, Z would monitor before purchasing the land from E to determine his potential liability to C and other rightsholders and adjust his offer price accordingly.

Thus, monitoring would be undertaken under either legal rule. Under the "first in time" rule, it would be done at Z's expense. Under the "last in time" rule, it would be performed at A's or E's expense. Moreover, there does not appear to be any difference between the quantity of monitoring undertaken under the two rules as long as the level of P_{ij} protection afforded to C and others remains unchanged.

The answer to the second question—whether C may sue anyone—involves considerations of equity more than economics. If C were given no protection at law from pollution by others, the pollution might still be reduced or removed if this were worth more to C than the payment necessary to get Z to eliminate the pollution source or to take other corrective action. If transactions costs were low, the optimal allocation of resources would be achieved regardless of whether C were given express protection.* Further, monitoring would probably be unaffected by a failure to give C legal protection. Rather than A or Z monitoring to avoid violating C's rights, C would incur monitoring costs to discover the extent of the pollution harm and the party with whom he could bargain to reduce or remove it.

However, if it is desirable on grounds of equity to give protection to C, there is reason to choose the "first in time" liability rule. This is because of the longevity of groundwater pollution. Since C may incur pollution damage long after causative action by A or his assignees, assigning liability to Z on the basis of the most recent ownership assures that C will always have legal recourse for damages. To free Z of liability against C could mean that C would have no recourse if A and other intervening owners of that land prior to its acquisition by Z were either deceased or difficult to locate. Also, assigning liability to the most recent owner avoids the cost of detailed title searches to discover which previous owner bears liability. Since the "first in time" rule has no offsetting increase in monitoring costs, it appears to be preferable on economic grounds.

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*See Coase (1960) and Section III, page 24, "Achieving the Efficient Solution."

Different possibilities arise if A sells only the southern half of his land to Z. C might incur pollution from both A and Z. A and Z might divide A's original waste relocation rights and duties in a fashion to assure that C's protection right was not violated. But if the exchange occurred and C's protection right were violated, then according to the "first in time" rule, C would sue Z first. If modifying or shutting down Z's pollution-causing activities were insufficient to achieve C's original level of pollution protection, then C could sue A too. As before, it would be undesirable to allow C initially to sue both A and Z together, and thus reduce the total pollution in the waters beneath C's land by apportioning the reduction between A and Z by some method (such as by the fraction that the size of A's and Z's land bears to the total area). While various methods of apportionment are possible, they would undoubtedly raise transactions and litigation costs.

Now assume that A sold only the southern half of his land in four portions to Z_1, Z_2, Z_3, and Z_4. Any subsequent violation of C's right to protection against more than 300 mg/l of chlorides would give C the right to sue any one of the four, or all of them together, as having violated A's original duty of not raising the chloride content above 300 mg/l in the waters underlying C's land, which duty both A and the Zs assumed after the exchange. If a suit against one or more of the Zs were insufficient to reduce the pollution under C's land to under 300 mg/l or less of chlorides, C would ultimately have recourse against A as well under the "first in time" rule. However many Zs there may eventually be, C would have the right to join one, two, or all of them in a lawsuit to protect his rights. If necessary, C could additionally sue A or whoever might have subsequently purchased the northern half of A's land, but this could only be done according to the priority sequence established by the "first in time" rule.

By the same token, if C subdivided his land and one or all of the Cs experienced a pollution violation, the Cs would have the same legal right against chloride pollution in excess of 300 mg/l as C himself initially had against A, Z, or any of the Zs. It is conceivable in this case that all the Cs would join together and sue all the Zs (if necessary including

A) in a single action rather than each of the Cs suing each of the Zs separately. This outcome is likely since transaction costs would probably be lowered (De Vany et al., 1969).

If numerous exchanges and subdivisions of land occur with the passage of time, the procedures for enforcement will grow increasingly complex. But this should not be taken as an argument against creating a waste relocation rights system of groundwater quality regulation. The increasing complexity which may result constitutes evidence that the rights to allocate land, groundwater, and allied resources to steadily higher valued users and uses is being accomplished through ordinary market processes. In spite of the apparent complexity, however, protection is granted in each case by two relatively simple legal rules. First, sales or subdivisions of land are allowed provided that they do not create pollution in the waters underlying any other owner's land which exceeds the pollutee's original right of protection (before sale or subdivision) unless he consents. Second, whenever a violation occurs, the pollutee has legal recourse against the most recent acquirer of land; that is, priority for protection from liability is given to the owners who are "earliest in time."

WASTE RELOCATION RIGHTS AND NONLANDOWNERS

Most of the foregoing discussion of the creation of a waste relocation rights regulatory system—the rights, their enforcement, and their exchange—has been limited to owners of land or their assignees, since most polluters and pollutees would be landowners or lessees of land. These owners or lessees would include nonprofit associations as well as the United States Government, all of which would be given every measure of protection under the waste relocation rights regulatory system that for-profit owners of land received.

The waste relocation rights system also extends protection to individuals and groups that do not own land. Since waste relocation rights are tied to land as covenants which may be sold separately from the land, landowners could transfer those rights to individuals or groups who seek not to pollute the qualities of groundwater but to preserve and protect them. Thus, environmental groups having a keen interest in improved water qualities might buy up important waste relocation rights and hold them "idle" for any use except pollution. This would be analogous to the Sierra Club and similar organizations now buying choice redwood stands, "using" these resources for such activities as recreation and visual enjoyment rather than for lumber products.

AN APPRAISAL OF SOME POTENTIAL PROBLEMS

In order for the system of waste relocation rights outlined in this section to achieve the optimal level of pollution, it must cope with several problems at a cost which is relatively low compared to achieving the optimal level of pollution control by other means such as discharge permits or effluent charges.

In general, the problems caused by the characteristics of the groundwater resource present no greater challenge to the planner of the waste relocation rights model than to the planner of the discharge permit model or the effluent charges model, providing that each planner has the same goal in mind; namely, achieving the economically efficient use of resources and thus the optimal level of groundwater monitoring and pollution. This subsection analyzes the viability of the waste relocation rights scheme in light of (1) the large number of transactors who would buy or sell rights; (2) the difficulty of monitoring groundwater pollution and of tracing it to the correct source; (3) the difficulty of predicting the movement of groundwater pollutants; (4) the longevity of some of these pollutants; and (5) the potential for some pollutants to combine synergistically. Each of these problems presents obstacles (costs) to the effectiveness of the waste relocation rights scheme. But the crucial question is whether these problems are more easily managed through waste relocation rights versus discharge permits or effluent charges.

The Large Number of Transactors

Defining rights to relocate wastes in terms of the overlying ownership of land raises the question of whether myriad owners of land or waste relocation rights would greatly increase the costs of exchange. If the cost of exchange often exceeded its value, then rights would not usually be allocated to their highest valued use and the economic benefits of the waste relocation rights system would be lost.

There are two reasons, however, that the large number of transactors should not hobble the exchange process. First, when two or more parties exchanged waste relocation rights, they would be required by law to negotiate with (compensate) only those third parties who would be adversely affected by the exchange; that is, those who would incur pollution in excess of their P_{ij} protection rights. This constraint would limit the number of parties that must legally be brought into any single transaction and reduce the potential number of expensive multisided exchanges.

Second, the number of owners of land or waste relocation rights would be greater than the number that would use land to pollute groundwater. (Analogously, oil companies seeking to drill under land that they do not own must purchase mineral leases only from the relatively few owners whose property would overlay the path of drilling.) The number of transactors would also be reduced since a municipal corporation (a city government) would be considered an "owner of land" as either a polluter of groundwater or a pollutee. Thus, defining groundwater waste relocation rights in terms of the overlying ownership of land should not increase the number of participants beyond those involved under a discharge permit regulatory system. The same consideration applies to the effluent charges regulatory system. The agency charged with setting effluent fees would have to survey and analyze a large number of economic activities in order to ascertain the optimal degree of pollution and the fee associated with it. Similar startup costs are involved with the waste relocation rights regulatory system in setting the initial P_{ij}. But once the initial P_{ij} have been determined, the market system is relatively self-regulating at little public expense provided exchange costs are kept low. This is not so for either the discharge permit or the effluent charges systems.

The self-regulating character of the waste relocation rights regulatory system should be emphasized. Although the initial P_{ij} would be set governmentally, they would be modified toward optimal levels through voluntary exchanges. This process would be similar to the manner by which parcels of land are exchanged, subdivided, and recombined into more valuable configurations. The price of waste relocation rights would fluctuate like prices of other resource rights, responding to forces of demand and supply. The prices would be established through competition among various groups in the marketplace. For example, environmental, recreation, and water-quality organizations would have incentives to bid up the price of waste relocation rights to use aquifers that are valuable for their purposes. They would "use" these rights by holding them idle—in effect, preventing pollution by bidding them away from pollution-causing uses and users and reserving them for conservationist goals. Other groups such as industrial waste disposers and municipal sewage systems would bid for waste relocation rights in order to inject pollutants into groundwater up to the allowable P_{ij} limits. Whichever individual or group had the greater demand would offer the owner of the waste relocation rights the highest price, suggesting that this would be the highest-valued social use of these particular rights. The advantage of the waste relocation rights regulatory system is that the quantity of pollution and groundwater quality monitoring would be determined through impersonal market forces rather than through the favoritism or lobbying that might accompany an administrative regulatory system.

The large number of transactors in the waste relocation rights scheme offers two additional advantages. First, there would be so many owners of rights that the possibility for monopoly gains from their sale would be rare. The main economic benefit accruing to owners of large parcels of land or waste relocation rights would be greater flexibility in planning their pollution-causing activities because of the greater possible distance from the point source to the boundary at which pollution could not exceed the legal P_{ij} maximum. The second advantage in having a large number of transactors is that a detailed administrative scheme or auction to distribute the rights to individuals would be unnecessary. This is because the creation of these rights would be tied to the existing ownership of land. The only requirement for getting the system into operation would be a tract index of land ownership and the hydrological-economic information necessary for setting initially usable P_{ij} limits on pollution.

Traceability

Under the hypothetical waste relocation rights regulatory system, it is essential that a pollutee be able, at relatively low cost, to trace the source of the pollution plume to the offending landowner or his assignee. But tracing groundwater pollution to its precise source can often be expensive. Monitoring along the edge of the pollutee's property may be insufficient to establish a valid damage claim in court, especially if the point source is several miles away. Models of groundwater pollution movements may not be sufficiently accurate to determine the exact source. Visual inspection of man's activities—e. g., an oil company's brine disposal pit being found "up plume" from a farmer's contaminated well—may give some clues as to possible sources. Such clues, however, might not support a court injunction to move the disposal pit, to otherwise dispose of the brine, or to compensate the owner of the farm land.

Monitoring is intrinsic to the problem of tracing groundwater pollution. But the difficulty of monitoring is not unique to a regulatory system based on waste relocation rights. The success of any regulatory system for pollution and monitoring—including one based on either discharge permits or effluent charges—ultimately rests on the costs of detecting, tracing, and predicting groundwater pollution. Thus, monitoring technologies, costs, and strategies are critical to any regulatory system which may be adopted. The workability and transactions costs associated with any chosen regulatory system, including waste relocation rights, will be only as sound as the quality and cost of the supporting monitoring and modeling techniques.

Predictability

The question of the predictability of groundwater pollution is a separate matter from its traceability to a source. The level of pollution will vary over time with rainfall and other factors. Although pollution may vary around some central tendency, it will not always be inexpensively predictable. Yet the property definition sets a flat nonstochastic limit of P_{ij}, not allowing for seasonal or other variations. Any instance of excessive pollution, some amount greater than P_{ij}, would be a violation of duty owed by one rightsholder to another.

This structure of the right is neither unrealistic nor inefficient for at least three reasons (De Vany et al., 1969). First, the constraint is a maximum, not a specific requirement. Second, pollutees would probably not incur the costs of court action if they expected the increased pollution in excess of the legal P_{ij} maximum to be minor or short-lived; small or infrequent violations, even if they endure for some time, are unlikely to raise a protest. Third, and most important, to write a stochastic definition of pollution into the property right—for example, that the maximum P_{ij} could not be exceeded by more than 5 percent during 10 percent of the time—would raise the cost of enforcing the right. However, nothing in the structure of the right prevents the polluter and the pollutee from voluntarily making a contract providing for a stochastic limit to pollution.

In sum, it would appear that the problems of the predictability and traceability of groundwater pollution would become manageable, i.e., sufficiently inexpensive, in the waste relocation rights model only if the engineering and hydrological sciences provide reasonably accurate and reliable groundwater pollution quality models. However, this is necessary for monitoring and pollution to be reduced to economic levels under any regulatory system.

The Large Number of Pollutants

The number of potential groundwater pollutants is large and the types vary tremendously—from chlorides to chromates to coliform bacteria. Each may harm aquifers differently depending upon the nature of the aquifer and the use to which it is put (e.g., a rice crop is more sensitive to salt pollution than is cotton or soybeans). Determining initial pollution levels when the number of pollutants is so great and the consequences so varied may be a difficult problem, but it is not unique to the regulation of groundwater pollution through a waste relocation rights scheme. Any system of pollution regulation—and the monitoring procedures implied by it—must set some permissible levels for each pollutant. These decisions are made differently under each of the three regulatory systems.

Under the discharge permit regulatory system, maximal levels of injections are set for each type of pollutant for each polluter, or permittee. This decision is similar to the maximal limits of P_{ij} that would initially be set under the waste relocation rights regulatory scheme. Hence, the large variety of pollutants which could make the waste relocation rights system complex and unwieldy also could cripple the discharge permit regulatory system. The same type of decision—setting some level of allowable pollution for a variety of substances and organisms—would be necessary under each regulatory system. However, the waste relocation rights regulatory scheme is superior in this regard to the discharge permit scheme. The initial limits for pollution rights must be usable and valuable for exchange but do not need to be optimal; rights can be exchanged and recombined to maintain a continuous optimum over time. Since the discharge permit system does not provide for exchanges of permits or voluntary and gradual adjustment of pollution levels, greater care must be taken under this regulatory system to set the initial maxima fairly close to optimality. Second, the optimum under any system will tend to change over time as populations, demands, technologies, and climates change.

A similar relationship exists between waste relocation rights and the effluent charges regulatory system. The agency charged with controlling effluents would, in all probability, have to tax not just effluent per se but different effluents differently. Again, this requires a decision similar to setting the initial P_{ij} of the waste relocation rights scheme in addition to setting the effluent charge expected to result in the desired quantity of each effluent. As with the discharge permit regulatory system, the effluent charges model requires an administrative agency to determine changes in the fee as populations and other circumstances change. This discrete administrative decisionmaking process also compares unfavorably to the gradual decentralized decisionmaking process associated with the waste relocation rights scheme.

Although the initial P_{ij} under a system of waste relocation rights should be determined only after careful hydrological-economic studies, one might tentatively conclude that to be economically usable they usually should be slightly in excess of existing pollution levels for aquifers that are relatively unpolluted. P_{ij} slightly in excess of existing levels would give landowners something to exchange and would reduce monitoring costs. The P_{ij} could be set at less than existing levels so as to be on the safe side, although this is not recommended since it would impose large capital losses on many landowners by forcing them to clean up underlying groundwater. It could also raise monitoring costs drastically.

Longevity of Pollution

Liability for groundwater pollution is complicated under any regulatory system by the historical distribution of pollution. Pollutants often move slowly through aquifers and may not cause harm until years later when the firm or individual who injected the pollutants is dissolved or dead.

Under the discharge permit regulatory system, protection can be provided for pollutees only by setting maxima for injections and monitoring inputs accordingly. Where the future consequences of pollution are expected to be especially severe, the discharge permit system would respond by lowering allowable inputs further and monitoring even more carefully. This response is open to several criticisms. First, the discharge permit system is cumbersome administratively. In general, it would not produce the correct value of monitoring information regarding the benefits and costs of decreased (or, for that matter, increased) pollution. Therefore, it would generate the optimal degree of pollution only by coincidence. Second, it is possible that more pollution would result than the administrative agency intended. This additional damage could be the fault of poor groundwater models, careless monitoring, or conditions beyond the agency's control (e.g., unpredictable rainfall). Third, the discharge permit regulatory system provides no mechanism to compensate pollutees for any damage incurred years later, especially for damage which is greater than anticipated administratively. As long as the polluter adheres to the maximum injections allowed by his permit and monitored by the agency, the future pollutee has no recourse against either the polluter or the agency. Fourth, the discharge permit system gives the polluter no incentive to reduce pollution below the maximum level specified in the discharge permit. Discharges below this level are "free" to the polluter but they may be costly to society at large, especially if the particular pollutants are long-lived.

Most of these criticisms can also be made against the effluent charges regulatory system. The polluter would adjust his effluent according to the specified tax, but the total amount of pollution and the effluent charge associated with it would both be set adminstratively. The only means by which the future consequences of long-lived pollution could be taken into account would be for adminstrators to raise the taxes for these substances. But fees would be difficult to determine administratively for a variety of pollutants and difficult to change once set. Under this regulatory system, any cognizance for future damage must be taken administratively since the polluter would not be liable for future damage as long as he paid the full tax associated with his particular emissions. Pollutees would not be compensated for greater-than-anticipated damages resulting from an improperly selected level of pollution or from imperfect groundwater modeling and predictions.

Under the waste relocation rights regulatory scheme, some protection is provided for future pollutees by linking liability to particular parcels of land. This is accomplished by two items of the waste relocation rights detailed in this section. In item 1 of the right, a polluter may not exceed the maximum P_{ij} unless these levels are changed through voluntary transactions among rightsholders which do not harm third parties without their consent or compensation. Hence, liability for pollution in excess of the level voluntarily agreed to is tied to the particular legally defined land area. This liability rule becomes a covenant that goes with the land as part of its title whenever it is sold. The second element of protection to future pollutees is provided by item 3 of the waste relocation right. This paragraph gives pollutees injunctive relief and whatever damages they can prove in a court of law as having been caused by the pollution. Since courts of law recognize the principle of discounting future income streams to present value in assessing damages in personal injury or death cases, they could allow for compounding past damage values to present values years later in accounting for the damage proved to have been caused by past pollution to groundwater. The skill of courts in awarding accurate damages from pollution would be closely related to the accuracy of monitoring and modeling techniques.

The critical distinction among the three regulatory systems is that the waste relocation rights regulatory system provides some protection to current rightsholders from historical pollution actions since the symmetrical right to pollute and the right to protection from pollution alike are tied permanently to the ownership or assignment of land.

A prudent buyer of land could reckon with this potential liability in two ways. First, before purchasing the land, he might ask to monitor groundwater to determine existing levels. In situations where the value of the land or the potential liability is large, he might even hire consultants to perform some modeling to predict future levels. This activity is exactly analogous to the termite or structural inspection of a home paid for by the buyer. Second, the buyer could engage in a title search in the cognizant government agency's register for waste relocation rights and liabilities in much the same way that an escrow or title insurance company is paid by prospective owners to guarantee the title of a piece of land or a house against debts or other encumbrances. If the waste relocation rights title search revealed liabilities which were especially costly for the purpose to which the prospective buyer expected to put the land, then he would lower or withdraw his offer price for it.

Transacting the Different Pollutants

Although the foregoing analysis has, for simplicity's sake, focused on transactions involving only one pollutant at a time, the actual number of pollutants is large. While this might appear to greatly increase exchange costs of a waste relocation rights regulatory system, two forces would work to reduce these costs. First, it is likely that only a few pollutants—perhaps a dozen or less—would be important in any particular geographical area. For example, a given level of boron and brines might ruin orange groves in Orange County, California, but would have little effect on industrial users around nearby Long Beach. This effect would limit the number of pollutants that pollutees would seek protection from. The second factor for reducing transactions costs would be exchanges covering more than one pollutant at once. Nothing in the waste relocation rights regulatory scheme requires transactors to contract for just one pollutant at a time. The monitoring, modeling, and legal services required to consummate one exchange of waste relocation rights for a single pollutant could be applied to others, "spreading" the lump-sum exchange costs over a variety of pollution possibilities. The costs of monitoring actual pollution and of enforcing contracts could be treated similarly.

Synergistic Pollution

This analysis has treated each pollutant as independent in the damage it causes; that is, as if the damage caused by pollutant P_4 could be separated from the damage caused by pollutant P_{120}. Nature, however, is not so simple. In some cases groundwater pollutants combine into fresh chemical compounds which tend to neutralize the harmful effects that might be caused by each separately. In such cases pollutees would suffer less harm than in the absence of one or more of the interacting pollutants. Thus, if the limit on one pollutant were technically violated, the pollutee usually would not take legal action if this "violation" were neutralized by the presence of some offsetting pollutant in the groundwater beneath his land. On the other hand, two or more pollutants might combine to cause the pollutee more damage than either would cause separately.

The pollutee is automatically protected to some extent by the waste relocation right if each of the two (or more) pollutants is generated by polluter A and if A exceeds the maximum legal limit for either or both pollutants. But the pollutee is not protected by the rights system, as it has been outlined, if A injects two chemicals which combine chemically to produce damage to the pollutee, provided each injection is within A's waste relocation rights of P_{4A} and P_{120A}. Protection of this kind would require expanding the P_{ij} list of pollutants to include synergistic compounds for A such as P_{4A} and P_{120A}. This modification is probably feasible although it would make the property system more complex.

Consider next the situation where the P_4 found under the pollutee's land is traceable to polluter A but the P_{120} is traceable to polluter B. The property system gives the pollutee recourse whenever P_{4A} or P_{120B} separately exceed the legal maximum, but this recourse is limited to either polluter in isolation. Allowing the pollutee to sue A and B jointly reintroduces the problem of apportioning liability between the two defendants, but this creates severe legal problems and reduces the possibility of achieving economically efficient recourse. In this respect, the synergistic combination of pollutants is similar to the problem of intermodulation among different radio emitters operating on different frequencies, again paralleling the analysis of De Vany et al., (1969).

Consider also the situation where the pollutee incurs damage even though A injects P_{4A} and B injects P_{120B} in amounts that fall within the legal maxima. As before, the property system gives the pollutee no protection against this form of synergistic pollution. This could be changed by extending the "first in time" liability rule to require in these cases that the most recent polluter either modify his operations or shut down in order to restore pollution under the pollutee's land to legal levels. However, this modification is not recommended for two reasons. First, it would greatly complicate the waste relocation rights system by requiring initial levels for not only the P_{ij} pollutants but for combinations of them from different polluters. This might require modification of some of the rules for making exchanges, and surely would complicate even the registry requirements of the rights system. The whole system would become less flexible and transactions costs would increase, especially if there were some apportionment of liability among different polluters. Second, it might be difficult for courts to determine what the critical cutoff levels of synergistic pollution for each polluter would be. Therefore, it appears undesirable a priori to give pollutees protection from synergistic pollution beyond that given where individual polluters violate their P_{ij} constraints and the harms from synergistic pollution can be traced to these violations.

The pollutee would still have options for reducing synergistic pollution even if the system of waste relocation rights did not provide formal protection. For example, he could pay A or B to reduce existing synergistic pollutants or to generate nonsynergistic pollutants. If the value of preventing this damage were less than the cost of making and enforcing contracts voluntarily, the pollutee's land would probably go unused or be allocated to other economic activities. This result is not undesirable if modifying the waste relocation rights system to take into account synergistic relationships between two polluters were to raise transactions and enforcement costs to the point of reducing overall economic efficiency.

SITUATIONS INAPPROPRIATE FOR WASTE RELOCATION RIGHTS

The waste relocation rights regulatory system can cope with most but not all pollution problems. It can even handle some complex pollution situations at an increased cost, but several pollution and monitoring problems appear to be beyond its scope of application.

Pollution involving large numbers of polluters and pollutees may not lend itself inexpensively to the waste relocation rights paradigm. Where thousands of septic tanks pollute the water used by hundreds of farmers "down plume," it would probably be uneconomic for each farmer to sue each septic tank owner separately even if pollution were traceable at low cost to its exact source. The damage caused by each polluter would probably be small (and hence his liability would be small) relative to the costs to the pollutee of proving damages. Moreover, the transactions costs involved in all the pollutees joining together to sue all the polluters might be great relative to the expected pecuniary gains unless each group were represented by a municipal corporation. The problem would be more tractable if both groups were represented by the same municipal corporation, so that liability is settled through local bargaining and political processes.

In the case where polluters or pollutees are unincorporated and the transactions costs of bargaining or taking legal action are relatively high, the economic solution appears to be to assign liability by regulations rather than to rely on market exchanges to determine the optimal amount of pollution and monitoring. If economic efficiency is the goal of public policy, then the liability in such cases should be assigned by statute to the party who can avoid the damage at least cost.

On the one hand, if it would be cheaper to regulate the design of septic tanks to reduce damage from leakage, then the polluters should legally be given this responsibility and the costs should be borne by them. Placing the liability on the owners of tanks would save extra transactions costs since pollutees would otherwise have to contract with tank owners to reduce damage. In this situation groundwater monitoring would amount to checking randomly on construction standards and leakages, probably by a public agency in rather the same way that other building code provisions are enforced. On the other hand, if fewer resources were consumed by having pollutees either treat the water polluted by septic tanks or adjust their activities in some other manner, then economic efficiency would command that they be given responsibility for adjustment. Again, failure to assign liability in this way would lead polluters to waste resources in contracting with pollutees to assume liability. In each of these cases, economic efficiency requires that liability be made unambiguous and be initially assigned to the least-cost avoider of the damage.

The waste relocation rights regulatory system could not be expected to allocate resources efficiently when pollution is not traceable at low cost to its point source. This matter can scarcely be overemphasized. Monitoring and modeling for information as to where pollution originates is essential for efficient resource allocation under this regulatory system. Corker's adage that the "effectiveness of law is limited by hydrogeology" applies equally to the effectiveness of market processes in allocating waste relocation rights (Corker, 1971).

The waste relocation rights system would also be inappropriate for pollution problems associated with "common pools." Consider the problems associated with seawater intrusion in the diagram depicted in Figure 31. Pumping from A's well lowers the water table to the point where A and B experience seawater intrusion, with B's salinity in excess of the hypothetical legal maximum of 300 mg/l of chlorides. Whether B has recourse against A depends upon the interpretation of the phrases "economic activities" and "originally degrade" in item 1 of the original waste relocation rights definition. A would be liable if the courts interpreted these phrases to include a failure by A to take into account the effect of his pumping on seawater intrusion into the aquifer beneath B's land. This would be a logical interpretation of the right if B would not have experienced pollution in the absence of A's pumping, which is considered to be an "economic activity." Alternatively, this problem could be handled under the body of law governing pumping from common pools rather than the waste relocation rights regulatory system.

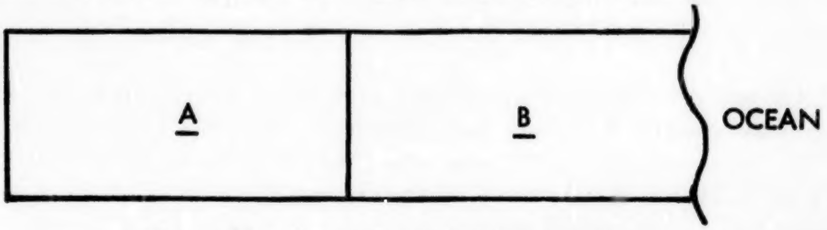

Figure 31. Seawater intrusion example.

A final problem that may not be handled inexpensively by the waste relocation rights regulatory system is pollution caused by nonpoint sources (such as sewer lines, road salts, etc.). Assume that a road coincides with the A/B boundary in Figure 31 and that it is salted during winter to the extent that more than the legal limit of 300 mg/l of chlorides is found in the groundwater under B's land. If the road is owned and salted by A or B there is no problem in placing liability provided the illegal salinity can be traced to the salting operation. If the roads are municipally owned and salted by a public agency, then liability is still clear, provided that it is politically feasible for public agencies to assume it.

Since the pollution rights regulatory system gives protection to groundwater underlying publicly owned land, it would be logical to assign liability to such public land in the same way that symmetrical rights and duties are assigned to privately owned land. If this assignment of liability is not practical, then landowners could be given protection against publicly caused road salt pollution only by municipal regulations or State-imposed regulations on municipalities that limited the quantity of salts in areas especially prone to saline pollution.

CONCLUSIONS

This section has compared and contrasted alternative pollution regulation systems and highlighted the relative attractiveness of the waste relocation rights system. There is an important relationship between this discussion and the analysis of monitoring in the remainder of the report.

Both the nature and extent of monitoring are dependent upon the pollution regulatory system adopted. The nature of monitoring and the value of resources devoted to it will be different when regulation is by discharge permits rather than by waste relocation rights. Both systems involve monitoring for information and for compliance. For example, monitoring by public agencies near sources of pollution would probably be more common under the discharge permit system; monitoring by private parties near the consequences of pollution would be more common under the waste relocation rights system.

A virtue of the waste relocation rights regulatory system is that monitoring would be done by private parties and would be largely "self-enforcing" through the courts. A large bureaucracy, a large budget, and large groups of "monitoring marshals" could be avoided while the Nation's groundwater quality would still be guarded in most situations under this regulatory system. Instead, private parties would take steps largely in their own interest to protect their individual waste relocation rights which would be steps in the national interest as well. Thus, the "privatization" of most monitoring would not only reduce costs to the general taxpayer and avoid the difficulties of centralized governmental administration but be more likely than any alternative to provide an economically efficient degree of protection to the Nation's groundwater supplies.

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APPENDIX

CONVERSION FACTORS

English to International System (SI) conversion factors for units used in this report follow:

Unit	Abbreviation	Multiply by	To find	Abbreviation
gallons per minute	gpm	3.785 412	liters[a] per minute	lpm
acres	not used	0.404 686	hectares[b]	ha
inches	in	2.540 000	centimeters	cm
feet	ft	0.304 800	meters	m
gallons per day per foot	gpd/ft	3.785 412 x gal 0.304 800 x ft	liters per day per meter	lpd/m
feet per mile	ft/mi	0.304 800 x ft 1.609 340 x mi	meters per kilometer	m/km
feet per year	ft/yr	0.304 800	meters per year	m/yr
gallons per year	gpy	3.785 412	liters per year	lpy

Notes:

[a] One liter = 0.001 cubic meter

[b] One hectare = 10,000 square meters

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